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Combined Abrasive Recycling and Containment - Final Report With Summary and Conclusions

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

in cooperation with
Peterson Builders
Sturgeon Bay, WI

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National Shipbuilding Research Program

Project Number 3-94-2

Combined Abrasive Recycling and Containment

Final Report with Summary and Conclusions

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I EXECUTIVE SUMMARY

This report describes how the NSRP Project 3-94-2, “Combined Abrasive Recycling & Containment System,” was conducted. The report includes brief descriptions of preliminary tasks involving information retrieval and the selection of a combined abrasive recycling and containment unit suited for shipyard use.

The bulk of this report describes the construction of a prototype of the combined abrasive recycling and containment unit. The containment unit was evaluated at Atlantic Marine in Jacksonville, Florida. Details are given of the evaluation and analysis of results from this prototype demonstration. Based on the results of the demonstration, a redesign of the containment unit was developed that incorporates many improvements.

From several alternatives the research team selected a mini-enclosure containment system. It used a commercially available rigid space frame construction fitted with waste collection hoppers and aluminum gratings for the working platform. The enclosure gained access to the ship hull from a truck mounted lifting arm. The platform had a 12-foot reach and approximately 125-degree yaw capability. The containment membrane and seals were designed to create a class 1A containment (highest degree of emission control). This required an engineered ventilation system to provide adequate air movement within the enclosure.

Arrangements were made with Atlantic Marine of Jacksonville, FL. to demonstrate the prototype to blast clean a preconstruction primer from the hull of a ship in drydock. The construction of the containment took about 3 days.

Various items were evaluated. The effectiveness of the containment unit in controlling emissions was measured. Efficiency in moving the containment on the lift was timed. Ability to properly clean the surface was determined. The adequacy of air movement and visibility inside the containment was assessed. The level of worker protection was measured, both inside and outside containment.

In almost all respects, the prototype met or exceeded the design criteria. The maximum production rate during blasting was about 600 ft^2 per hour per operator. The overall productivity (taking into account the movement of containment and other nonproductive activities) was about 300 ft^2 per hour. (The movement of the containment took about 4 to 5 minutes). Air samplers placed outside the containment indicated dust levels of less than 0.100 mg/m^3, which is well below the level set by OSHA for worker health effects. Abrasive reuse efficiency was estimated at 97.5%, exceeding our design goal of 90% abrasive reuse. A total of about 1600 square feet were blast cleaned.

A number of modifications are suggested to improve the efficiency and practicality of the prototype. These include reduced size of the containment, and of the footprint of the lifting device, along with improvements in seals, bellows, membranes, lighting, movement and rotation of the platform.

An economic analysis is given for the implementation of the redesigned containment at a typical shipyard. Costs are estimated for abrasive blasting to two levels of cleaning, Near White Metal - SSPC-SP 10 and Brush-Off Blast - SSPC-SP 7. The cost to achieve these levels of cleaning are compared for the current prototype, Containment with Recycled Metallic Media (CRMM), and for a control, conventional Open Air Abrasive Blasting (OAAB). Also considered is whether the waste generated is hazardous or non-hazardous. If the waste is non-hazardous, the prototype containment system (CRMM) is about 30 to 50% more costly per square foot than the conventional method (OAAB). This does not

take into account the benefit of reduced dust and debris in the general shipyard area. If the waste is hazardous, the containment system is less costly than open air abrasive blasting. The time required for return on investment in a CRMM system depends upon the efficiency of abrasive reuse. With an abrasive reuse efficiency of 95%, the pay-back period for return on investment is less than three years (when a hazardous waste is generated).

II INTRODUCTION

A Objective

The objective of this project was to demonstrate a way for shipyards to improve the efficiency of their paint removal operations by adapting the methods of abrasive recycling and containment developed in related industries. For a containment to be successful it is critical that the structure designed conform to four criteria:

- The containment must match with existing space allowances in shipyard dry-dock;
- The containment must be compatible with existing shipyard rigging and scaffolding equipment;
- The containment structure must be adaptable to a number of vessel sizes and types, and;
- The containment structure must represent an economically sound investment.

B Understanding of The Problem - Background

1. Current Shipyard Practices

The repair and maintenance of marine vessels provides an important source of income for many U.S. shipyards. One of the tasks facing the painting department of a shipyard, when conducting maintenance work, is to complete cleaning and recoating of various portions of the ship hull while in dry dock. A common surface preparation process involves an abrasive blasting method with mineral abrasive. This process generates large quantities of airborne dust, which is often hazardous. Air quality regulations require control of hazardous airborne dusts. Thus, there is growing examination in the marine industry of methods to limit dust emissions from surface preparation. One of the methods used to control such emissions in other industries is a containment system, often with the use of recyclable metallic abrasives.

In many yards, new construction of marine vessels involves descaling of plates and structural members using centrifugal wheel blasting facilities. On occasion a yard may elect to conduct a portion of their surface preparation efforts in a blast and paint room. Both of these types of facilities often use recyclable steel grit in a controlled continuously ventilated area. By way of contrast, it is more rare for a yard to use recyclable steel media for abrasive blasting of a vessel in dry-dock. (Such practice has been evaluated as an alternative in an earlier NSRP project, NSRP Report 0378, although this application did not use a containment system). The present project uses a combined abrasive recycling and containment system of modular design. To our knowledge the type of design used in the current project has not previously been demonstrated at a shipbuilding and repair facility.

2. Driving Forces for Containment

   Several imperatives may drive a move toward an enclosed contained work area for the types of exterior blasting described above. Typical examples of such driving forces include:

   - Restrictions of ordinary (nuisance) dust emissions from abrasive blasting;
   - The presence of a potentially hazardous material in the coating system, such as:
     - Heavy Metals - Lead, Chromium;
     - Toxic Anti-foulant compounds - Organo-Tin, Copper;
   - The presence of a potentially hazardous material in the abrasive:
     - Silica, Arsenic, etc.

   Regardless of the reason for attempting to restrict emissions from exterior abrasive blasting, the net result is a need to contain the work of surface preparation.

3. Impact of Containment on Shipyard Work

   The use of a containment in shipbuilding and repair will obviously impact the manner in which work is conducted. From prior experience in the use of containment structures several impacts will be noted. Potential negative impacts include the following:

   - *Increased exposure to hazardous air pollutants in containment* - When removing a coating containing a heavy metal or using a mineral abrasive, worker exposure to respirable dusts can increase markedly while in a containment. Adjusting the rate of air flow through a containment has been shown to offer comparatively little help in reducing levels (based on the experience of the bridge and tank painting industry in handling high airborne lead dusts from old lead-based paint removal activities). This factor can best be addressed by use of other engineering controls, or proper personal protective equipment;
   - *Reduced productivity* - All containments need to be moved around or across a structure. While in transit, a containment is not in use, nor is any useful work being performed in the containment. The result is lost production compared to uncontained abrasive blasting. In addition, a worker blasting inside a containment can lose productivity on two counts. First, a containment may make for an uncomfortable cramped work setting with poor visibility due to dust build-up. Second, if a heavy metal containing material is being removed, the level of productivity may be further reduced by the need for improved worker protection.

     Many of these issues can be addressed at the design stage. Judicious choice of containment dimensions make it easier to maintain a clean atmosphere. They can also improve working conditions by leaving adequate working room. Reducing the size of a containment can improve its mobility. Finally, visibility in a containment can be greatly increased by the use of explosion proof lighting fixtures, or a more transparent containment membrane.

Potential beneficial impacts from the use of containment structures can include:

- *Improved efficiency of abrasive use* - The practice of using a recyclable abrasive reduces abrasive consumption, thus minimizing waste volume. A net improvement in abrasive use will result in a direct cost saving to the yard.
- *Improved surface finish quality* - Surface finish quality cannot be compromised by the need for containment. Fortunately, the use of a containment structure can actually improve surface cleanliness. This is because the contained area is shielded from the elements and has a controlled atmosphere. As a consequence the surface contained can be maintained in quality for longer periods of time following the blast.

The influence of these factors as they impact shipyard surface preparation and coating activities is not synergistic. Sometimes these factors work in opposition to one another. For example, optimizing the design for improved access, visibility, and hence productivity can increase the size of the containment. Too large a containment results in inadequate airflow, reducing worker protection. The research team designed a system which optimizes key aspects without compromising overall containment utility or practicality.

4. Previously Examined Alternatives to Open Air Abrasive Blasting

The marine community has been examining a variety of alternative approaches to surface preparation. Each of these methods has benefits and detractions compared to traditional open air abrasive blasting. In a related NSRP project (3-94-1: “Controlling Hazardous Airborne Dusts in Shipyard Surface Preparation and Coating”) five of these methods were highlighted for review (with open air abrasive blasting included for benchmarking purposes). The methods examined included:

- Small Area Touch-Up and Repair by power tools - (SATR) Reduces dust and waste, but at greatly reduced production rate and decreased surface quality; cost is relatively high per square foot.
- Low Volume Water Slurry Blasting - (LVWS) Greatly reduces waste and dust with a slight decrease in productivity; relatively high volume of waste requiring disposal.
- High Pressure Water Jetting - (HPWJ) Greatly reduces waste and dust; relatively high productivity and low cost per square foot, but gives reduced surface quality.
- Vacuum Abrasive Blasting - (VAB) Reduces dust and waste; high surface quality; significant reduction in production rate and increase in cost per square foot.
- Containment with Recycled Metallic Media - (CRMM) Which was examined under this project. High productivity with highest quality surface achievable; reduces waste by recycling, reduces dust hazard, requires significant capital expenditure and results in relatively high cost per square foot.

C Contents of Prior In-Progress Deliverables

A number of in-progress deliverables were provided to the NSRP under this project. These deliverables include:

1. Task A - Technology Review

   a) A Survey of Existing Technology - Information Search.

   This survey provided information on the following areas of information:

   i) Experience of Other Industries - Highway Bridge and Water Tank Lead Paint Removal

   ii) Experience of the Marine Engineering Community

   iii) Shipyard Working Conditions

   iv) Review of Technical Literature

   v) Codification of Criteria - a database which summarizes the content of articles based on relevant keywords or keyword combinations.

   b) A Survey of Shipyard Requirements

   Marine industry surveys to determine the size and form factor constraints on a containment design imposed by dry-dock working conditions. This activity also provided information on typical equipment available at a variety of sites.

   c) An Evaluation of Selected In-Use Systems

   This provided information on selected state-of-the-art containment systems when used in general industry.

2. Task B - System Selection: Choose Existing System Closely Matching Shipyard Needs

   Based on the foregoing activities a combination of existing system components was defined in a system selection statement. This provided the basis for choices made during the design and evaluation phase.

3. Task C - Design and Demonstration of Containment System

   a) Delivery of Design Drawings for Selected System

   Design drawings and associated AutoCAD (Level 12) drawing files were delivered which defined the design concept proposed for the field evaluation phase.
   These deliverable items are described in the appendix to this final report. The design files themselves are available from NSRP Program management.

   b) The Report on Field Demonstration of the Prototype Containment

   This report described the following areas of activity conducted by the research team:

   - Designing the prototype shipyard containment structure.
   - Background information - what lead to the project, how the project coordinates with others' efforts and a brief description of how the project team prepared for this Task C design and demonstration phase.
   - Objectives and Scope of Task C, including:
     - An outline of the design goals and expected containment capabilities.
   - What was done in the design and implementation phases of Task C.

- Arrangements for shipyard demonstration of prototype containment.
- Construction and evaluation of a prototype containment.

The report also provided the following assessment of the demonstration containment:

- Complete description of design and performance goal attainment based on the field trials.
- Description of proposed design improvements based on field trials.
- Delivery of final (improved) modular abrasive recycling and containment design.
- Estimation of return on investment for implementation of improved design.

Complete design drawings for the containment system demonstrated were provided in the Task C Report, along with revised designs that incorporate improvements suggested by the demonstration activities.

III PRELIMINARY TASKS

A Technology Review

A carefully designed information review was conducted to determine the state-of-the-art in blasting containment design and abrasive recycling unit capabilities. This information search included a review of the background literature, a survey of both general industry and the marine community on containment use and design preferences, and field evaluations of in-use containment systems. The full report for this deliverable is available from NSRP program management.

1. Literature Information Search

The literature review was conducted with emphasis placed on identifying those practices which minimize wasteful consumption of abrasives and those containment designs which are optimized for use with recyclable abrasives. Over 1000 literature abstracts were examined and copies of over 200 articles were obtained. Of these, only 62 literature sources were identified as being relevant to this project. Topics which were discussed in our report on this literature survey are described below.

a) Experience of Other Industries - Highway Bridge and Water Tank Lead Paint Removal

Because a primary driving force in the design of containment structures is the removal of lead paint from bridge and tank structures, the search targeted information based on highway and water utility use. A detailed survey, the same one sent to three shipyards, was also answered by a contractor removing lead paint on a water tank.

b) Experience of the Marine Engineering Community

The literature was searched for containments and abrasive recycling related to shipbuilding and ship repair.

c) Shipyard Working Conditions

Information was sought on the operating conditions under which a prototype containment might have to operate in a shipyard setting. Information was gathered from seven shipyards about the type of ships they painted, the minimum and typical clearances, the type of containment (if any) they used, and other pertinent information. A more detailed survey was conducted of three of these shipyards and the one industrial site mentioned above.

d) Review of SSPC Technical Libraries

Since lead paint removal has been a topic of major interest at SSPC for the past decade, the SSPC library has many references dealing with lead paint removal, recycling of abrasives, and containment.

e) Compilation of Abstracts

Data on articles of interest were entered into a computer database. Individual articles were accompanied by a brief descriptive abstract.

2. Survey Shipyard Requirements

To supplement the literature review, a survey of the paint departments at US shipyards was conducted. The survey questions concerned types of abrasive used, current and anticipated containments, environmental regulations, size of vessels, and physical parameters of the

dry dock.

3. Evaluate Selected In-Use Systems
   In order to evaluate the effectiveness of containment systems currently in use, site visits were made to two shipyards and to a water tank. The water tank, with its curved surface, was judged to be better than a bridge in approximating a ship.

4. General Trends from Technology Review
   The technology review provided useful insights on the compatibility between different design options and shipyard requirements. In particular, the following general statements can be made:
   - The use of containment and abrasive recycling is growing in both general industry and shipbuilding.
   - Concerns about hazardous paint removal (principally lead containing paint) drive the use of containment and abrasive recycling in the general industry but may or may not affect shipyard decisions.
   - The level of containment employed is often also a response to local or political pressures in addition to technical requirements to conform to environmental regulations.
   - Steel grit or other metallic abrasive is used in the general industry when recycling and containment are employed. Although shipbuilding typically uses mineral abrasives, some of these facilities are moving toward the exclusive use of metallic abrasives.
   - The general trend in the painting industry is to move to the use of engineered containment and designs. The shipbuilding industry is using both simple and higher grade containment materials and designs.
   - The one coherent guide to containment design is SSPC-Guide 6. It is useful in defining design terms, but does not depict typical shipyard abrasive recycling and containment requirements. Guide 6 provides tabulated information that guides a user to determine the level of containment effectiveness needed for a particular task. The guide defines four classes of containment and includes materials which are essentially single use. This guide was written primarily for maintenance activities at field sites. A second important publication is “Project Design,” the second volume of the Industrial Lead Paint Removal Handbook. This book provides a means to incorporate a sub-structure of Guide 6 into a decision framework resulting in an overall project design.
   - The needs of shipyards are quite different from those of typical field sites. As capital facilities, they can amortize the increased cost of investing in more durable, higher grades of containment materials. Field sites typically use a containment system once. Many costs for field containment systems are applied to a single project.

5. Shipyard Specific Issues
   In addition to the general comments listed in the previous section, there are some specific issues which arise from the shipyard visits and phone surveys.
   - There is no “one size fits all” abrasive recycling and containment design. Work piece and work area dimensions differ considerably from yard to yard.
   - The types of containment needed in a shipyard can be divided into three general classes:

    - <u>Ad hoc project specific</u> containments using flexible materials;
    - <u>Semi-permanent reusable</u> containments for large structures using interior support structures, and;
    - <u>Semi-permanent modular</u> containment enclosures for small sections of a structure compatible with existing moving equipment in the shipyard.
- To achieve compatibility with current shipyard operations, designs must permit the use of recyclable mineral abrasives.
- The kind of abrasive recycling compatible with shipyard operations is either
    - <u>Point source recovery</u> - vacuum blasting;
    - <u>Integrated recovery</u> - such as an auger screw conveyor to continuously recover abrasive, or;
    - <u>Periodic recovery</u> - i.e., recovery of spent abrasive at the end of each shift.

B Select Existing System Closely Matching Shipyard Needs

The research team in conjunction with the SNAME SP-3 panel selected a system that most closely met the criteria for containment suggested by the advisory group. Some of the requirements were: Class 1A containment as defined in SSPC Guide 6; mini-enclosure type; constructed with rigid framework, walls, and floors; 99.5% abrasive cleanliness after recycling; and at least 90% of the abrasive is reused.

1. Review of Containment System Components & Design Parameters

a) Overview of Design Characteristics

The containment system includes the following components:

- Materials for the containment structure support;
- Equipment for containment structure support;
- Materials for containment platform;
- Materials for containment membrane;
- Support equipment for dust removal, and;
- Support equipment for abrasive recycling.

Our method was to take readily available components from general industry. These were then adapted for shipyard use.

b) Materials for Containment Structure

The main assumption made in approaching the containment design was that materials of construction should be both lightweight and durable. This would permit the containment system to be used on a prolonged basis in a shipyard setting.

Containment structure materials are used to support the walls, to provide flooring and for general support. Not all structural materials used for containment systems in other industries have prolonged durability. Sometimes plywood or similar lightweight materials are used. The design team carefully selected the structural elements for the shipyard containment such that they would provide long-term durability. It is expected that the shipyard containment system would be used over several months, or years, without a need to repair or replace critical structural materials. To this end the primary materials in the prototype design are aluminum. Aluminum piping is used for support of the membrane

fabric (see Figure 1 on page 12). Aluminum grating is used for the flooring, and aluminum sheet metal is used for the integral abrasive media feed train.

c) Materials for Containment Membranes

There were three goals in selecting the containment membrane material. First it should be durable, able to withstand indirect impact from high speed abrasive particles and generally robust. Second the membrane should permit reasonable lighting within the containment area. Third, as hot work is prevalent in ship construction, the membrane fabric should have a measure of fire resistance. There was only one membrane fabric which met these requirements in all three areas, a proprietary material called Monarflex. Consisting of a tinted polymer film built onto strengthening polyester threads this membrane:

- Withstands indirect abrasive impact, even direct abrasive blasts from four feet distance will not immediately shred the membrane.
- Provides good light transmission being white in color, and;
- Has a Class C fire rating (it contains built-in fire retardant pigmentation).

The Monarflex membrane also has easy repairability using supplied two-sided adhesive tape. In the event of damage from prolonged abrasive blast material contact, the containment could be back in running order within minutes.

The appearance of the constructed containment unit is shown in Figure 2 on page 13.

Figure 1: General Design Concept - ARK Platform

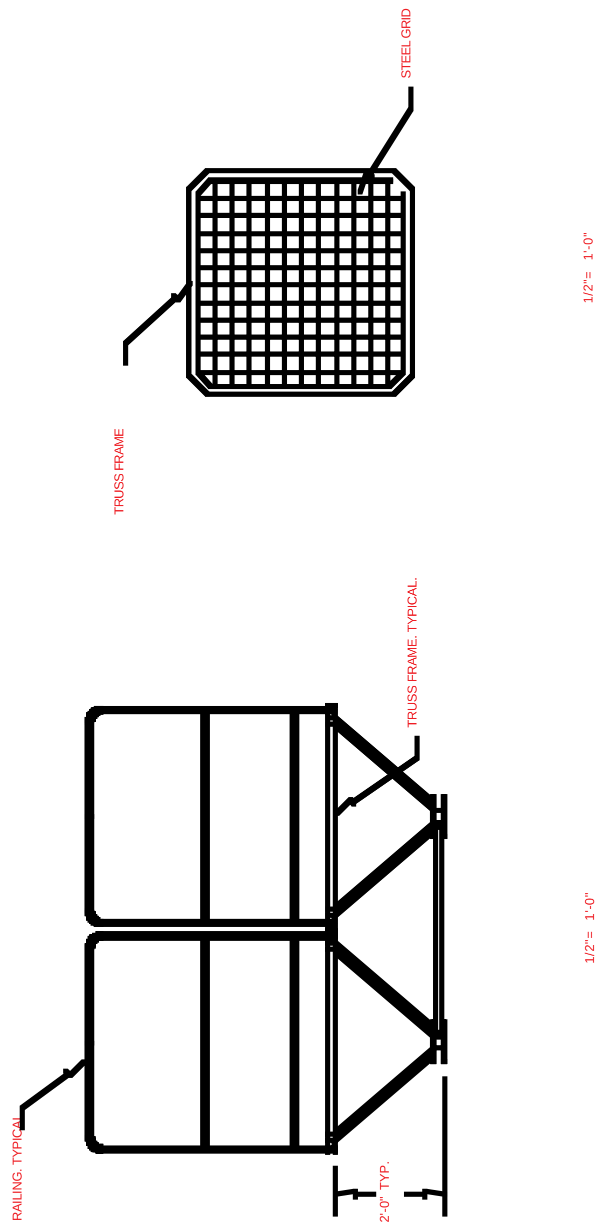

Figure 2: ARK Platform with Monarflex Material (from Field Trials - Jacksonville, FL)

d) Rigging Requirements

There are two ways to match shipyard requirements for rigging of a containment. The first calls for the enclosure to be free from the vessel, fully self-supported by a lifting device. The second requires integration with the drydock setting. Our mandate called for an adaptable “modular” containment. This mandate steered us toward choice number one as it is independent of vessel and drydock configuration. (NSRP and other research groups had also examined in detail the two primary means of matching an enclosure with a vessel. One in which the entire drydock area is “enclosed” with a cover piece, the other in which an enclosure is strung from the top of a vessel. Our choice of using a self-supported structure avoids duplicating this prior effort of others).[1]

e) Ventilation System

The requirements for ventilation and dust collection systems are interdependent. The choice of dust collection and ventilation systems was made to meet performance criteria. The goal was that working at full capacity the velocity of the air moving in down-draft through the containment would be well above 100 feet per minute.[2] Another constraint on the choice of ventilating equipment is that the footprint of the equipment be small enough to fit in the confines of a large number of drydock settings. Finally, we wanted to be sure that fuel and or electric power requirements matched commonly available power sources, e.g., 110V AC, 220V AC, or the use of diesel fuel. Commonly available compressors from Ingersoll-Rand readily met our needs providing compressed air capacity in the range of 80-140 psi with over 400 CFM. This overcapacity of compressed air is critical to the successful use of the containment. Long hose runs were anticipated as our containment structure was to be placed to the ship hull at high elevations. These long hose runs lower the pressure delivered at the nozzle to the blaster. To maintain productive pressures (90-110 psi) at the nozzle demands far higher pressures at the compressor.

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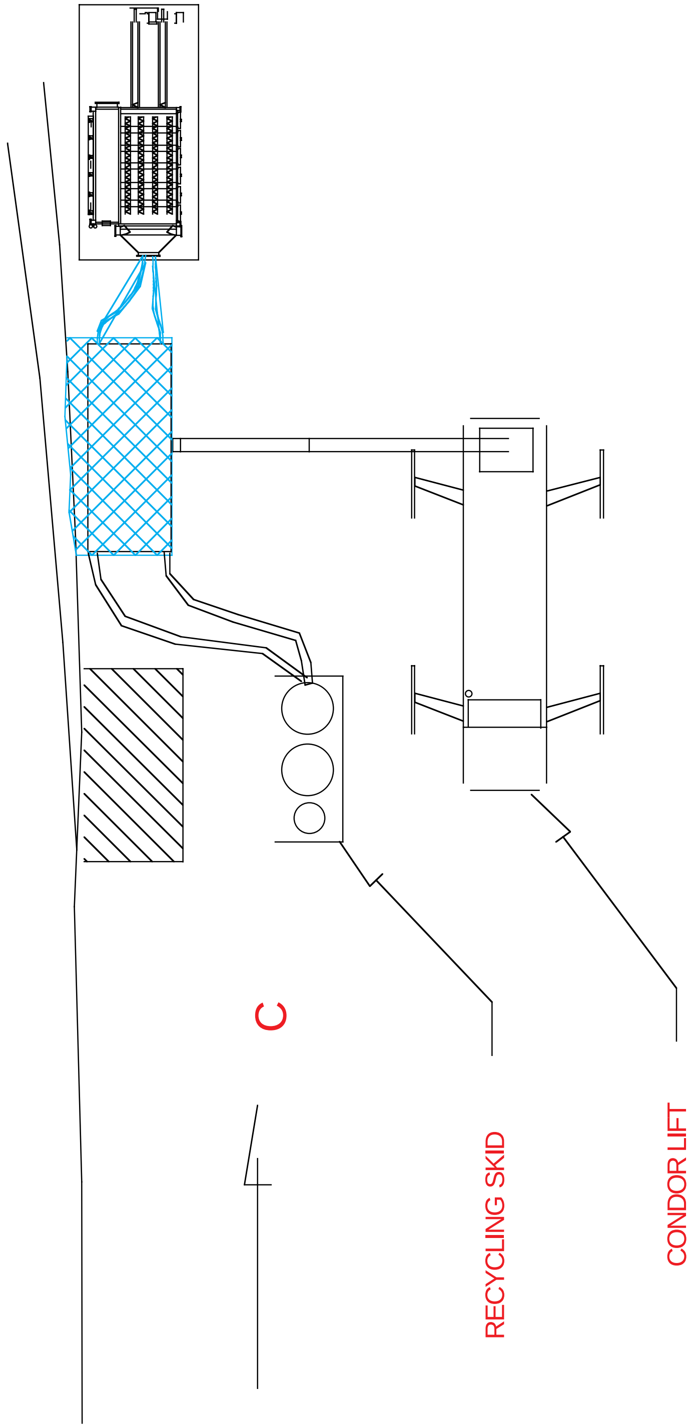
1. NSRP Projects 3-93-6 “Use of Recycled Media in Tank Blasting” and 3-95-1, “Total Dry-Dock Enclosure System.”
2. This exceeds the guidance levels for air movement in containment given in SSPC-Guide 6; these follow Industry guidelines of 60 fpm minimum (downdraft) and 100 fpm minimum (cross-ventilation). Such air movement goals are intended to maintain visibility in abrasive blasting rooms.

Figure 3: Lifting Device With Platform



f) Dust Collection System

The capacity of the dust collector was critical because of the need to maintain the minimum face velocity required within containment. The listed capacity of the dust collector was 12,000 CFM (Ingersoll-Rand), which provided a significant margin of safety in the number of available air changes per hour. A margin of safety is needed because a dust collector will often not function at peak capacity. The second critical performance criterion for the dust collector was its efficiency. The objective was to contain essentially all the dust generated during blasting. In part this is governed by the negative pressure created when the containment is placed against the ship hull. (This stops immediate escape of light airborne dusts). In part it is governed by the collection efficiency of the filter media in the dust collector itself. The chosen dust collector unit had a rated efficiency of capture for dust of 99.5%, matching our design goal.

g) Abrasive Recycling Equipment

The modular containment assumes use of recyclable abrasive to improve the economics of the cleaning operation. Recycled abrasive must be as clean, (or nearly as clean,) as new media. This goal demands that the abrasive recycling equipment have high efficiency in cleaning abrasive of dust or other fine matter. Such efficiency also helps in maintaining a correct balance of abrasive particle sizes in the working mix of abrasive. The abrasive recycling equipment should return the maximum quantity of usable media back to the blast pot. Our design goal was to provide greater than 90% return of usable media to the blast pot (this includes allowances for loss of heavy media from the containment itself). To meet this goal we anticipated that a recycling unit with an efficiency of > 99% reclamation of spent metallic abrasive feed would be sufficient. A commonly available abrasive recycling unit (IPEC VB-VacuBlaster 1200) was chosen to meet this design goal.

h) Lifting Device

The lifting device for the chosen containment had to provide high stability and lifting power in a small footprint. For the purpose of the prototype, the design used a Condor lift. This gives a lifting capacity of over 2500 lbs in a maximum of 25 m.p.h. cross-winds and a typical reach of 125 ft. The lifting device has all mechanicals placed on a flatbed. The device can be taken around the country on the open highways. Such mobility comes at the expense of an increased footprint. The lift and containment arrangement is shown in Figure 3 on page 14.

i) Containment Platform and Media Handler

The original design drawings were based on the use of a platform manufactured by Beeche Systems. Prior to the demonstration the designs were changed to reflect use of an ARK platform. This change was made because the Beeche platform was unavailable. The design includes an integrated material handling of spent abrasive. This is achieved by use of an auger feed underneath the base of the containment. The design also calls for the ability to gang containment units together to increase effective working area. The number of such units one can gang together is dictated by the capacity of the lifting device.To achieve our design goals the basic containment module chosen was an ARK mobile platform. The choice of this style of platform also gave us the lower weight and higher durability of aluminum for materials of construction.

2. Alternative Design Approaches

   Before settling on a precise combination of components, containment sizes and utilities, we examined (and discarded for different reasons) a number of alternate design approaches. Examples include:

   - Total dry-dock containment, this was discarded as it is already being examined by a separate NSRP project, (3-95-1, Alaska Dry-Dock sub-contractor).
   - Non-mobile containment - i.e., strung or rigged by attachment to the top of the hull wall. This was discarded as it was a design already examined in other yards, (such as at Sparrow's Point, PA).
   - Other Mini-Enclosure style containment. This was discarded because it provided a much smaller working area on the side of a vessel. The net result might be increased non-productive time spent moving the enclosure from one work area to another. This design, shown in Figure 5 on page 18, did provide inspiration for our field prototype. It also belongs to the class of freely mobile containments supported on a mobile crane or hoist.

3. Description of the Prototype Containment

   The prototype containment was designed to meet a Class 1A containment as described in SSPC Guide 6. This class provides the highest level of emissions control.

   It was a mini-enclosure type. Its internal dimensions were approximately 8 ft wide, 12 ft long, and 8 ft high (from working platform). Height was 11 ft from base of abrasive recapture bin to the top of the work area. The containment could accommodate two blasters. In the demonstration only one blaster occupied the structure at any time. This was done to keep within new weight constraints caused by the addition of 300 pounds to the dead weight of the system. The added weight came from temporary use of a bracket extension to fit the platform to the lifting device.

   The prototype containment had rigid frame construction based on an ARK Systems Corporation 8'x8'x12' space frame platform. The ARK platform was configured with waste collection hoppers and aluminum gratings for the work decking. Waste and recyclable steel grit were transported from the hoppers by mechanical grit removal and pneumatic dust collection.

   The containment membrane was an impermeable membrane tied to a skeleton of 2 inch schedule 40 PVC tubing which was itself secured to the ARK platform. The election to use PVC tubing was made to compensate for the added weight of the 3/8-inch galvanized steel channel bracket extension. This was needed to accommodate the depth of the ARK platform as it attached to the Condor lifting device. The final design, incorporating changes made to the lift by Condor for a permanent lifting device, eliminates the need for such a fabricated extension. This allows us to restore the more durable aluminum tubing to the design.

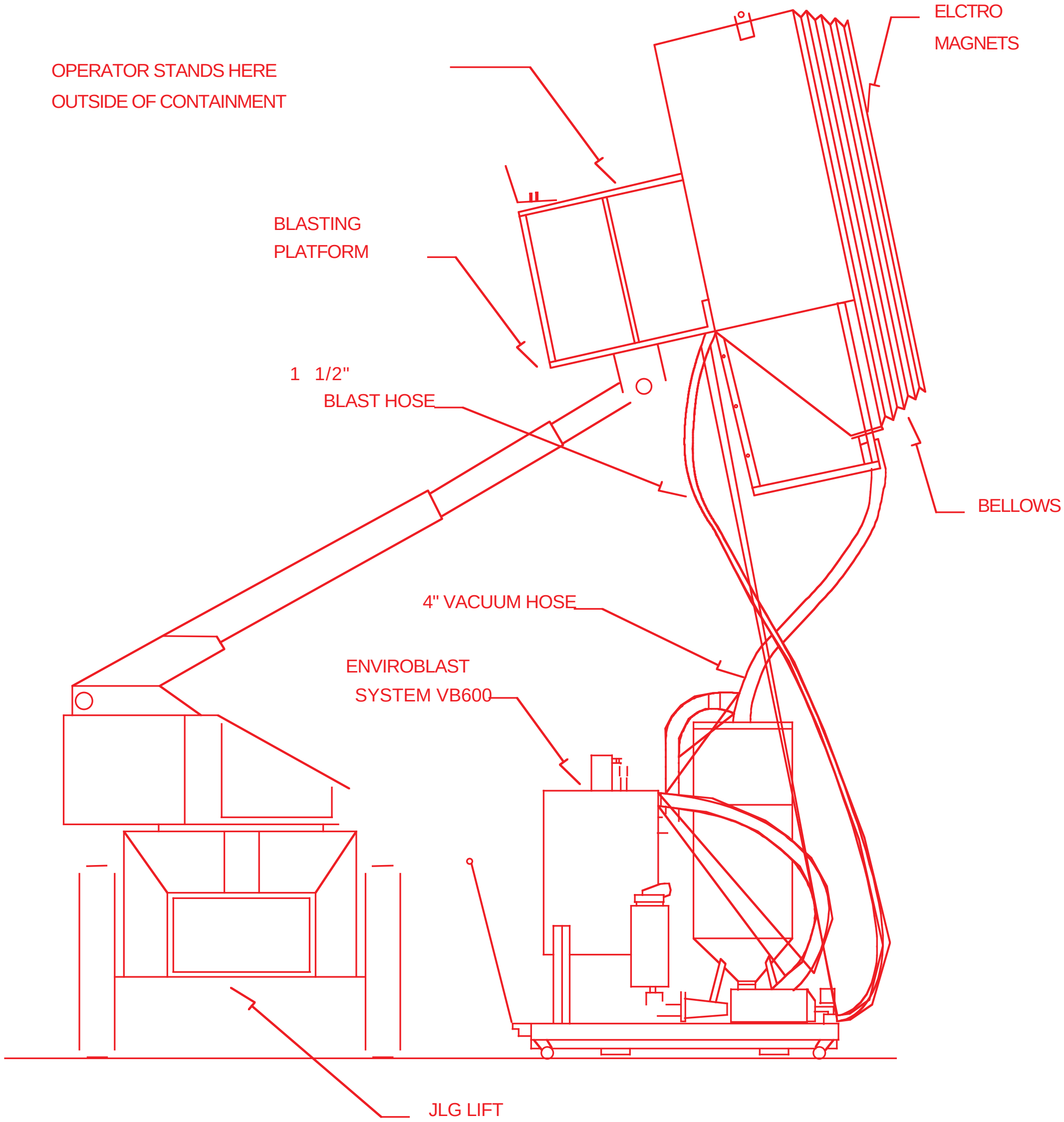
   The prototype was lifted into position using a Condor truck mounted 125S-TC. The ARK platform attached directly to the galvanized steel extension bracket. The bracket was attached to the fork blades of the lift, see Figure 4 on page 17. Controls for the boom were mounted to the Condor lifting platform, this was a change from our original design concept. This change is not required in our revised design.

Figure 4: Temporary Extension Bracket Used for Demonstration Exercise

Although the containment membrane materials can be either rigid or flexible, the prototype containment tested at the shipyard used flexible membrane material. The flexible membrane reduces the weight of the containment structure, which, as configured, weighed approximately 2000 pounds. The membrane bellows formed a seal with the walls of the ship using pressure. All joints were full seal and an open face entry was provided. Down-draft ventilation was chosen because it offered better air control and worker protection. There was natural input air flow and make up air was controlled. Air pressure was verified by instruments. Air was sucked into the hoppers below the feet of the blast operator. Take off ports in the collection hoppers are designed to remove airborne dusts to the HEPA dust collector. Dust collection was specified to achieve 99.9% filtration of 5 micrometer or greater size particles.

This design, featuring a platform structure on a boom lift, was chosen for its steadiness and mobility. The mobile platform used had a 125 foot reach (25% larger than our original design goal) and yaw capability. The lifting device can withstand 25 m.p.h. winds while sustaining a lift of 2500 lbs capacity. Because it is a self contained mobile unit, there are no additional rigging requirements.

Figure 5: Alternate Design Concept - EnviroBlast with Magnetic Bellows.



C Arrange for Prototype System Demonstration

1. Identify Participating Yard

Well over a year was spent trying to find a location where we could demonstrate the prototype containment system. The first demonstration site was identified in mid-1995. Preliminary arrangements were made for a demonstration as early as December of 1995. Unfortunately, the planned demonstration was cancelled (May, 1996) at the request of the shipyard for reasons unconnected with the project goals. A second demonstration facility was identified after this time, but preliminary arrangements were broken off when both parties realized that our demonstration goals did not meet the yard's expectations. This second facility did help identify our third yard prospect, Atlantic Marine of Jacksonville,

FL. In early April 1997 a firm commitment to the project was made by Atlantic Marine. By mid May, the process for prototype system demonstration and evaluation was underway. This began with consolidating all vendor supplied equipment used in the demonstration. (Acknowledgments for all supporting vendors are shown in Section VI on page 51).

Figure 6: Abrasive Recycling Equipment Used in Demonstration

2. Construct Optimized Containment System
   The construction of the containment took approximately three working days. Several changes were made from our original design plans (without sacrificing primary performance goals) to meet weight requirements or to integrate the various vendor components with one another.
   With the cooperation of the host shipyard and participating vendors, the prototype containment was constructed near the drydock. Connections were made between the containment and support equipment, such as the abrasive recycling unit seen in Figure 6, above. The containment was then used for surface preparation on hull sections coated with pre-construction primer.

IV Results and Discussion

A Field Evaluation of Prototype Containment

1. Goals and Design Criteria

   Several factors were planned for examination while the containment was in use:
   - Actual occupancy of containment versus target occupancy;
   - Dimensions of containment;
   - Actual rigging needed - motors, hoists, cables, compared with that anticipated;
   - Level of emissions during blast cleaning and criteria used;
   - Capacity of air-moving equipment, CFM design goal vs. CFM achieved;
   - Face velocities in containment, desired versus achieved;
   - Negative pressure in containment, expected versus achieved;
   - Containment seal efficiency - at seams and at junction with vessel being cleaned;
   - Review of materials of construction - containment system floor, walls and containment to structure seal or skirt;
   - Maximum hose length for abrasive feed to blasting nozzle, and for recovery of abrasive for return to recycling unit;
   - Records showing time to set up containment;
   - Documents showing operating procedures for all components of the system under examination;
   - Ease of movement of containment across vessel surface;
   - Surface cleanliness achieved in containment - based on SSPC Vis 1 - 89;
   - Incidence of damage to or contamination of previously cleaned surfaces by movement of containment enclosure on structure;
   - If applicable, coating film quality achieved by application within containment;
   - If applicable, incidence of damage to coating film caused by movement of containment across structure following coating application, and;
   - Sampling of the new and recycled media to determine achieved level of abrasive cleanliness and percent of abrasive recycled.

   Based on these evaluations, information was to be obtained that quantified the capacity of the prototype system to meet performance criteria.

2. Description of Unit Demonstrated

   The original design submittal for the prototype containment included a list of materials and equipment. This list was changed prior to demonstration in two ways. First, there were changes made to the identity of certain items of equipment. These changes were made only when our original choice was unavailable. Second, there were some changes made in the field. Any field changes were made on a contingency basis, to accommodate new equipment, or to maintain containment weight within safe limits. In Table 1 on page 21 are the equipment and materials for the containment prototype and those from field use.

Table 1: Comparison of Prototype and Field Containment Designs

Item Description	Prototype Item	Field Use Item	Reason for Change	Impact on Use
Platform	Beeche	Spider ARK	Availability	None
Lift Device	Condor 145	Condor 125	Availability	Unit supplied has larger footprint and older control mechanism. Required ground controller. Required added fork support.
Fork Lift Extension	None	Made in field	Mating Lift to Platform	Added Weight 300lb.
Membrane Support	Aluminum Struts	PVC Struts	Reduce total platform weight.	Less durable than aluminum struts.
Membrane material	Monarflex	Monarflex	N/A	None
Dust Collector	Ingersoll-Rand 12000 CFM	Ingersoll-Rand 12000 CFM	No change - but field use item performed at 45% of capacity.	Required adjustments to containment ventilation.
Plenum	None	Made in field	Improve containment ventilation.	Improved containment ventilation.
Grit Recycler	IPEC VB-Vacu-Blaster 1200	IPEC VB-Vacu-Blaster 1200	N/A	N/A
Compressor	Ingersoll-Rand	Ingersoll-Rand	N/A	N/A
Blast Pot	Standard	Standard	N/A	N/A

3. Description of Field Data Collected and Operations Conducted
   Factors we planned to examine during the demonstration of the containment were listed earlier in Section 1 on page 20. The only factors from that list not examined during the containment demonstration were those concerned with coating application and coating quality. This is because no testing was performed to determine the utility of the containment during coating application.

B Analysis of Results

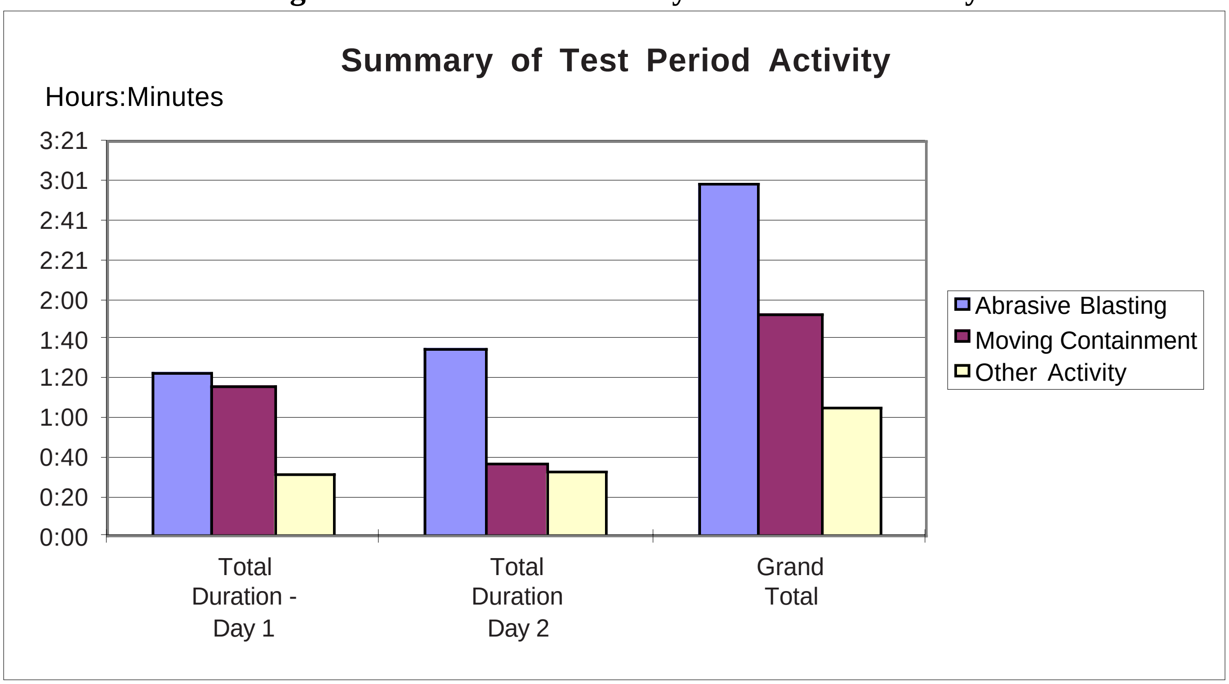
1. Productivity Assessment
   The duration of key activities from the containment testing is summarized for each of the testing days and in grand total in Table 2 on page 22, below.

Table 2: Durations of Primary Containment Activities

Activity Type	Total Duration (h:mm) - Day 1	Total Duration (h:mm) - Day 2	Grand Total (h:mm)
Abrasive Blasting	1:24	1:36	3:00
Moving Containment	1:16	0:37	1:54
Other Activity	0:32	0:33	1:06
Daily Totals	3:12	2:46	

This data is also shown as a bar chart below in Figure 7.

Figure 7: Containment Activity Distribution Per Day



The time required to move the containment was reduced relative to productive blasting time on day 2 of our testing. This is attributed to improved operator familiarity with the placement of the containment system against the vessel. Overall the ratio between productive blasting time and time required to move the containment from both days is roughly 1.6:1, thus over 60% of the testing time was spent in productive blasting work. The ratio between productive blasting work and containment movement on day 2 is 2.37:1, that is nearly 70% of the time was spent in productive blasting, less than 30% in moving the containment.
The production level is assessed using three parameters; blast productivity, general (work)

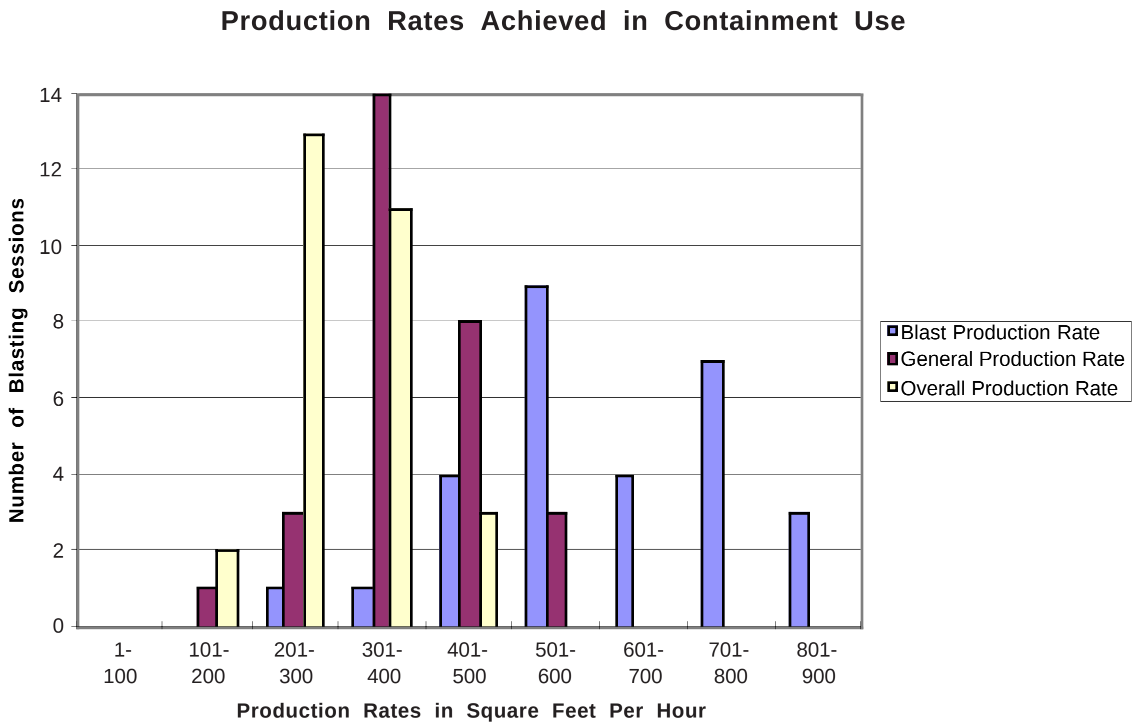
productivity, and overall productivity, defined as follows:

- Blast productivity - the number of square feet cleaned per hour while blasting took place in each session;
- General productivity - the production rate during blasting and containment movement activities, and;
- Overall productivity - the production achieved in all working hours measured.

Approximately 60 to 70 ft^2 of surface was cleaned in each blasting activity. The typical productivity for each blast period, along with an overall production rate is given in Table 4 on page 25. A graph displaying blast, general and overall productivity is shown below (Figure 8).

Un-recorded activities also took place which are indirectly associated with the set-up of the containment demonstration. These include getting clearance to the areas for use of the containment and clearing any mechanical problems at the beginning of the day. As a result, the total of recorded activities is approximately 3 hours per day of testing.

Figure 8: Production Rates During Blasting in Containment



The production rate estimates shown above are also included in Table 4 on page 25. Productivity differed between blasters. Two blasters occupied the containment, one on each day. Their respective productivity achievement is shown for blast productivity in Figure 9 on page 24.

Figure 9: Blast Production By Blaster

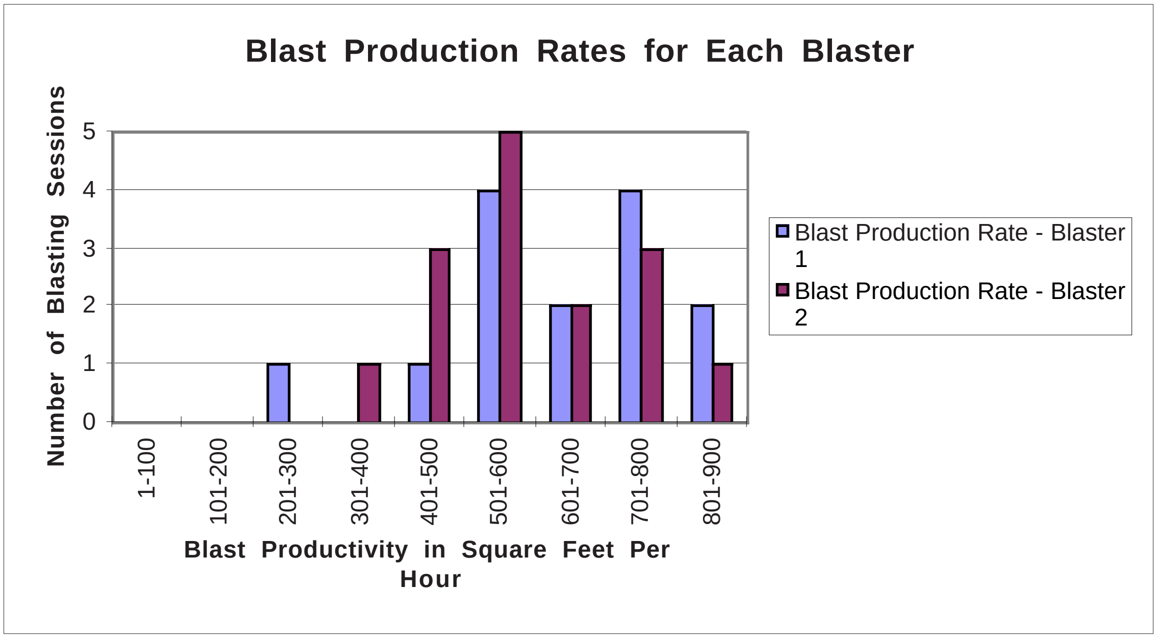


Table 3: Total Dust Concentration (mg/m^3) at Various Areas Near Blast Work

Sample #	Location	Total Dust (mg/m^3)[a]	Blasting Day
JP051497-01[b]	60 ft south of ship, 60 ft east of bay	0.065	No
JP051497-02[c]	60 ft south of ship, 20 ft east of restroom	<0.017	No
JP051597-01	60 ft south of ship, 16 ft east of bay	0.041	No
JP051597-02	60 ft south of ship, 20 ft east of restroom	0.020	No
JP052097-01	60 ft south of ship, 16 ft east of bay	0.018	Yes
JP052097-02	60 ft south of ship, 40 ft east of restroom	0.087	Yes
JP052197-01	60 ft south of ship, 16 ft east of bay	0.100	Yes
JP052197-02	60 ft south of ship, 40 ft east of restroom	0.207	Yes

a. PEL (8 hr TWA) = 15 mg/m^3 for total particulate, measured in accordance with NIOSH Method 0500
b. 01 = Background Measurement - Sample IDs correspond to initials of industrial hygienist, date of sample, and type of measurement. Sample IDs are also used to identify position of sampler location in Figure 10 on page 27.
c. 02 = Work Area Measurement

Table 4: Productivity Rates Inside Containment[a]

Minutes Blasting[b]		Blast Productivity (ft^2/hr)	General Productivity (ft^2/hr)	Overall Productivity (ft^2/hr)
	13.0	277	169	139
	5.0	718	438	360
	6.3	570	348	286
	5.3	677	414	339
	4.9	735	449	368
	4.5	794	485	398
	7.3	497	303	249
	4.0	900	550	451
	7.0	518	316	260
	5.7	637	389	319
	6.6	547	334	274
	4.7	769	470	385
	6.7	535	327	268
	3.7	964	589	483
	6.0	598	366	300
	5.5	653	399	327
	6.1	587	359	294
	4.9	742	453	372
	5.1	704	430	352
	3.7	977	597	490
	7.3	495	303	248
	6.7	536	327	269
	8.5	424	259	213
	6.1	592	362	296
	10.9	330	202	165
	4.7	761	465	381
	7.1	508	310	255
	8.0	452	276	226
	5.6	641	392	321
Median:	6.0	598	366	300
Average:	6.2	625	382	313

a. Blast Productivity reflects the production rate achieved during each blasting session. General Productivity reflects both the time spent blasting and time spent moving the containment. Overall Productivity makes allowance for these two factors and also time spent in other engineering efforts such as debugging of lift equipment, recharging abrasive, etc.
b. All cleaning was to an SSPC-SP 10, “Near White Metal Blast Cleaning.”

2. Worker Safety and Health Inside Containment

The concentration of total dust was measured at various areas in the shipyard, (Table 3 on page 24,) as well as inside and outside the protective helmets of the blasters, (Table 5 on page 26). The data clearly show that the workers were well protected from any dust hazard. Comparison of dust levels inside and outside of containment demonstrate that the containment ventilation system did a superb job of providing entrainment and capture of dust generated during blasting operations. (Despite the acknowledged fact that the dust collector was operating at less than 50% of design capacity). Thus, workers outside of the containment would also be protected.

A quantitative assessment of worker protection was attempted by taking personal cassette particulate measurements within and outside of the blasters helmet, see Table 5, below. Two blasters provided data for the project on sequential days. Each blaster wore Type CE blasting helmets. Data from day one is when seal operation was optimal. Data from day two is when seal operation (and hence the number of air changes) was less than optimal. The data shows that within the blasting helmet both blasters saw dust levels of a similar order to those measured 60 ft away from the work area. Levels outside the helmet were between fifteen and 250 times those inside the helmet, higher ratios coinciding with the days on which poor functioning of the seals was suspected. In all cases the readings inside the helmet, taken over an eight hour day, do not exceed levels for worker protection from nuisance dusts, as mandated by OSHA (15 mg/m^3). Thus, the protection factor provided by abrasive blasting helmets was from 15.5 to 252. Visibility within the containment was described as acceptable by the blaster.

Table 5: Total Dust Concentration (mg/m^3) Inside and Outside Blasting Helmets

Sample #	Location	Dust Concentration[a] (mg/m^3)	Protection Factor
JP052097-01	Lorenzo Smith - Blasting helmet interior	0.114	252
JP052097-02	Lorenzo Smith - Blasting helmet exterior	28.8	
JP052197-02[b]	Alphonso Carey - Blasting helmet interior	0.340	15.5
JP052197-01	Alphonso Carey - Blasting helmet exterior	5.26	

a. PEL (8 hr TWA) = 15 mg/m^3 for total particulate, measured in accordance with NIOSH Method 0500
b. Readings taken on 5/21/97 coincide with poorer functioning of seals.

3. Control of Environmental Emissions

We measured the impact of dust emissions by visual monitoring of emissions and by personal air monitoring.

a) Visual Emissions

There were very limited visible dust emissions from the containment. Visible emissions only occurred when the blaster approached close to the seal edges. The volume of air

emitted by the blast nozzle was then sufficiently strong to overpower the containment seal, resulting in small visible puffs of dust.

b) Air Sampling

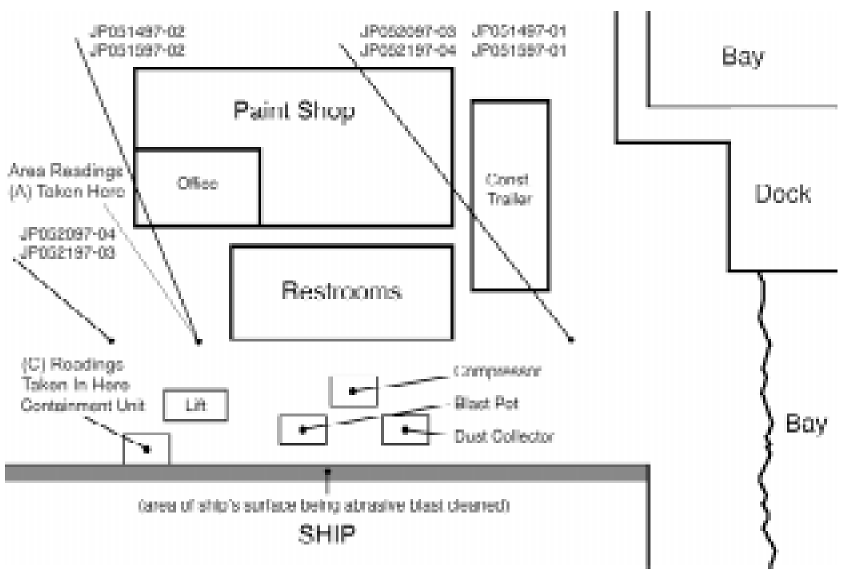
The data shows that the level of dust on days when blasting occurred was of the same order as that when no blasting was performed, if the containment seals were fully operational (Records from 5/20/97). When containment seals were not fully operational, (5/21/97), there was roughly a doubling of airborne matter collected by the monitors. (This was also a particularly active day for spray painting in the same area, a potential contributory factor). All other surface preparation for the pre-construction primer was conducted using pressurized water jetting. The results of our area monitoring are shown in Table 6: “Estimating Containment Efficiency by Area Monitoring” on page 28.

The area monitored and monitor placement is shown in Figure 10, below. A typical monitor is shown in Figure 11 on page 29.

c) Efficiency of Containment

One measure of containment efficiency proposed by SSPC uses results of area samples, both inside and outside of containment, made with personal cassettes. The area readings outside of containment are divided by the readings within containment (outside of the blasting hood), subtracted from 1.0 and multiplied by 100.

Figure 10: Placement of Area Monitors During Containment Evaluation



The result of such a computation is shown below in Table 6.

Table 6: Estimating Containment Efficiency by Area Monitoring

Area Reading (A) mg/m^3	Reading Inside Containment (C) mg/m^3	Efficiency 100(1 - A/C)
0.087	28.2	99.7
0.207	5.28	96.1

These estimated containment efficiency ratings indicate that the enclosure worked well when the seals were operating properly (with 0.3% maximum emission). Such estimates do not directly account for contributions to ambient levels from other dust or fume generating activities. They are best suited to analyzing the efficiency of a containment in retaining an individual hazardous dust (such as lead on bridge paint removal activities).

d) Comparison to Other Industry Data

The general background readings for dust emissions compare well to levels of emissions found in other paint removal activities involving containment use. For instance, Dawson et al found that on bridge paint removal projects the level of airborne dusts *outside* of containment ranges between 0.4 to 8.5 mg/m^3, even when a "sophisticated" bridge containment system is used. This suggests that our containment system performs at least as well as similar containment systems in other industrial applications. The referenced review of containment efficiency also estimated the efficiency of each of three containment structures in preventing lead emissions.[1]

1. "Containment Efficiency: Environment and Worker Exposure," Dawson, J. L., et al, SSPC Compliance Conference Proceedings 1997. Report SSPC 97-03, Pages 5-9.

Figure 11: Typical Area Monitor Using Personal Cassettes

4. Recycling of Abrasive (Degree of Capture & Reuse)
   A key performance goal was that 90% of the abrasive shall be recycled. Our greatest concern was with the amount of abrasive which might be lost through seal inefficiency.

   a) Means Used to Improve Seal Efficiency
   To help improve the mating of the seal edges with the vessel we used a spring loaded piston arrangement to help keep the seal in place against the vessel over non-uniform contours.

Figure 12: Piston Arrangement Used to Help Place Membrane Seals Against Vessel

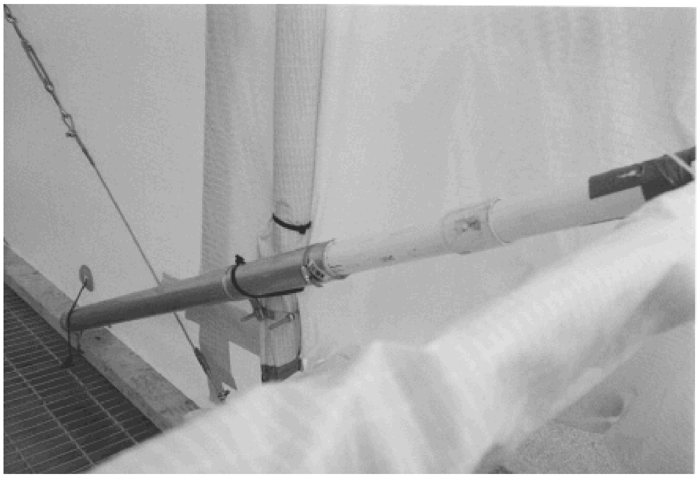


Figure 12, above, depicts this arrangement. The spring loaded pistons, like the rest of the skeleton of the containment, used PVC tubing which is placed into an aluminum sheath. The intention was that the blaster move the containment unit close to the hull, then place

the upper and lower membrane seals by extending the PVC pistons. This arrangement worked only for a limited period of time. Within the first day of blasting the PVC pistons became immovable, as grit had clogged the aluminum sheath. To assess the utility of the membrane seals in preventing the escape of heavy abrasive media we elected to place the containment on flat sections of the vessel wherever possible.

On the first day of full blasting we could find many such flat areas on the hull of the vessel. On the second and third days we had to conduct blasting on both flat sections and on sections with irregular surfaces. Thus our grit recovery on the second day was lower that on the first day of testing

b) Abrasive Recovery Efficiency With Functioning Seals

When we had access to smooth surfaces with fully functioning seals we lost less than one-tenth pound of grit per square foot blasted. As over ten pounds of grit are used to clean each square foot we were able to recover and clean 99% of the abrasive. The suggested design improvements to the seals (part of the improved design) are anticipated to routinely meet expected performance criteria.

c) Abrasive Recovery Efficiency With Poorly Functioning Seals

When blasting on irregular surfaces, especially with poorly performing seal setting pistons, abrasive media losses increased to up to 2.5%. We expect such losses to be the exception with our improved seal design.

NOTE: The maximum loss of abrasive over a day of blasting (consisting of eighteen blast events, each of around 60 ft^2) was estimated by collecting falling media from a 25 ft^2 area central to the work area locations used that day. Media fallout from the containment extended over an area of around 400 ft^2 close to the vessel. It was most dense at the sample collection area.The amount of abrasive collected from this one day of blasting (in which some 600 ft^2 of area was cleaned) was about 10 lbs. Extending the amount of collected sample over the entire fall-out area gives a total deposition of 10 x 16 lbs, or 160 lbs of uncaptured abrasive. The total abrasive consumed for this section was about 6500 lbs. (based on 100 psi, a #8 nozzle and 1.5 hrs of blasting).

Thus, even on a worst case basis where one assumes our sampled area is representative of the entire fallout zone, the projected losses of 160 lbs represents about 2.5% of the total grit passed through the nozzle.

C Summary of Design Goals Vs. Performance Achieved

The actual test achievements in relation to the design goals are summarized in Table 7, below.

Table 7: Comparison of Design Goals to Test Achievements

Item	Result	Comment
Degree Of Containment	SSSPC Class 1A	Highest Level Met Design Criterion
Dust Emissions	<0.017 To 0.207 Minimal Visible	Negligible Impact On Yard Air Quality
Negative Pressure In Containment	1.0 To 2.0 In Of Water	Exceed Industry Standard Of 0.03 In Water (Minimum)
Visibility In Containment	Adequate	
Dust Inside Containment	5.3 To 28.8 mg/m^3	OSHA PEL = 15 mg/m^3 (So Respirator Needed)
Dust Inside Helmet	0.114 To 0.340 mg/m^3	Worker Protected
Air Flow In Containment	Down-draft readings ranged from 120 to 200 fpm.	Exceed Industry Standard Of 100 fpm (Cross-draft) And 60 fpm (Down-draft)
Containment Mobility	Reposition In 4 To 6 Minutes	Resulted In Acceptable Production
Blasting Productivity	1000 To 1200 ft^2/8-Per Day	Comparable To Other Industries, Could Be Improved
Degree Of Surface Cleanliness	SSPC-SP 10	Similar To Standard Yard Operation
Containment Construction Time	3 Days	
Abrasive Cleanliness	Less than 0.5% Non-Magnetic Material.	Conforms to SSPC-AB2.

As indicated, each of the criteria was met with the evaluated containment system.

D Revised Containment Design

As a result of the field trials of the containment system a number of improvements is suggested.

1. Reduction in Containment Structure Dimensions

The tested containment structure was based upon an “off-the-shelf” ARK systems platform. This is a structure with a large floor surface area, designed for use under bridge decks. It has a footprint which allows it to fit neatly between under deck supporting girders on girder overpass structures. This footprint is not needed for shipyard use.

Our design improvement calls for a reduction in footprint from the tested 8x8x12 ft to a less deep section of 3x8x12 ft

A reduced footprint has several impacts on the operating characteristics of the

containment and abrasive recycling unit:

- First, this drastically reduces the dead weight for the platform. (The weight as tested was 2000 lbs; weight in the new design for the platform with an operator is 1200 lbs).
- Second, this decreases the load lifting capacity needed by the lift.
- Third, the depth of the platform now matches the default depth of the supporting structure provided in a Condor high-reach lift. Thus, there is no need for the added bracket support of 300 lbs of galvanized steel used in field demonstration unit.
- Fourth, the effective volume of the containment is cut in two. This has important impacts on the ventilation of the containment.
    - With a dust collector of identical capacity the same number of cubic feet per minute are moving through a space of half the original volume.
    - This will double the number of air changes per hour in the contained space.
    - Improved visibility and reduced dust levels during blasting will result.

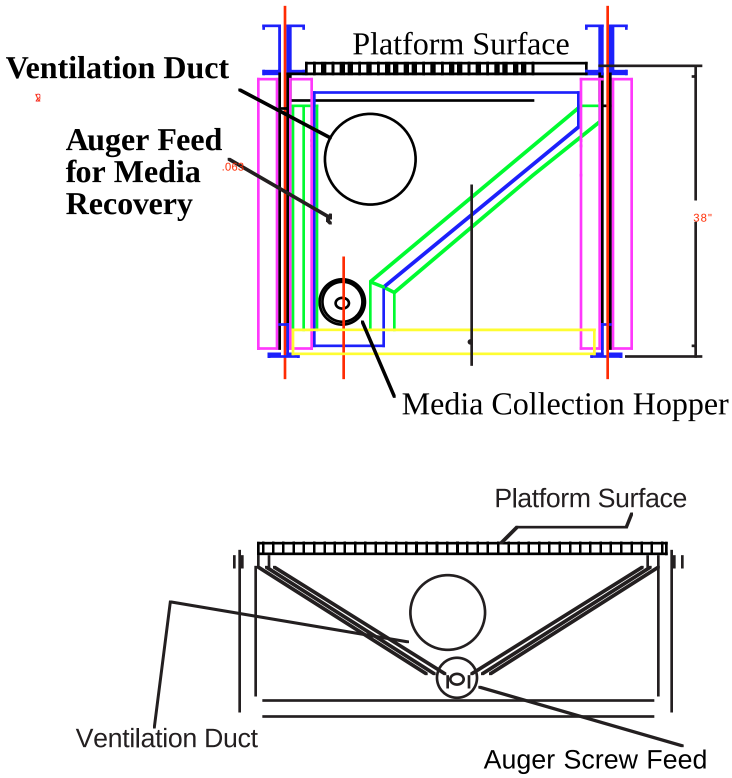
The primary benefit is the weight savings. This translates into improved stability, enhanced compatibility with the Condor Lift, and increased weight allowance for more durable structural elements elsewhere in the structure.

2. Improved Bellows Seal Control
   The piston loaded bellows became inoperative due to clogging with grit early in our field tests. The improved design calls for the use of gas shocks. These are gasket sealed to prevent entry of abrasive grit during use. The gas shocks are retracted prior to placing the containment close to the vessel. After initial placement the bellows are extended through activation of the gas shocks. This provides a more uniform sealing of the bellows against the vessel.
3. Improved Bellows Construction
   The bellows used in the field demonstration were constructed of double overlaps of membrane material, strung on spring tensioned coated wire. These showed signs of distress from short duration direct impact from abrasive. They also tended to accumulate abrasive in small pockets. This abrasive had to be cleaned out periodically, adding to non-productive time. The improved bellows are made of 3 inch stiff bristle brushes. This is closer in kind to the type of arrangement originally seen in the EnviroBlast module, seen in Figure 5 on page 18. Such a bellows construction adds approximately 150 lbs to the dead weight of the structure.
4. Improved Membrane Durability
   It is suggested that the final containment design use a membrane material which is more rigid than the evaluated MonarFlex membrane. The Monarflex membrane performed reasonably well in the field trials. But, with a view to the continued use of such a containment over an extended period of time, a more rigid and durable substitute has two key benefits.
   - First, the more durable material will reduce down-time for refitting and repairing containment membrane fabric.
   - Second, a rigid membrane provides a greater sense of security to a blaster working on the platform.

For other reasons elaborated below we suggest the use of clear rigid sheets of Plexiglass as the replacement membrane material. This will add approximately 50lbs to the dead weight for the containment.

5. Improved Containment Lighting/Visibility
   One of the early lessons learned in the use of the containment was that easy communication between blaster and ground was critical to getting work done. By using rigid clear plexiglass the ground and operator have a clear view of one another and communication is improved. Lighting and visibility within the containment also improve with the suggested materials of construction.
6. Increased Rigidity of Containment Skeleton
   Our field trials opted for the use of PVC tubing as a skeletal support for the membrane material. This was a temporary design change to facilitate the use of a weighty bracket extension to support the deeper ARK platform dimensions. We revert to the use of aluminum tubing to support the new rigid plexiglass skeleton. This improves structural integrity.
7. Improved Balancing of Containment Platform
   The ARK platform used in the field trials has its hopper designed around the mid point of the platform base. This is a suitable design choice for situations such as bridge girders where equal support on both edges of the platform is possible. This arrangement places the center of gravity of the platform out toward the edge of the supporting forks of the lifting arm of the Condor Lift. Our improved design moves the hopper backwards toward the lift base by canting at an angle of 45° to the vertical. This will greatly improve stability and wind loading for the device when attached to a Condor Lift. This design change is shown in Figure 13 on page 34.

Figure 13: Shifting Containment Platform Center of Gravity New (Top) Old (Bottom)



8. Reduced Footprint for Condor Lift
   The Condor Lift used in the demonstration had a large footprint when in use (25x40 ft) because the supporting outriggers were made quite long. The increased length of these outriggers was demanded because the Condor Lift used was road-capable. Being designed to travel on any major freeway the flat-bed (or base) on which the lift stood was made lighter to improve fuel efficiency when underway. A design optimized for fixed site use has a much heavier base, on which the lift and extension arm sits. This is achieved through placement of added weights to the flat-bed. This allows one to shrink the flat-bed base width and the width of the outrigger extension legs. The result is a smaller footprint. The lift remains mobile within a shipyard, but it is no longer road-capable.
9. Improved Operator Navigation of Platform
   The primary navigation controls are placed back onto the platform as is typical of all Condor Lifts. Redundant (over-riding) controls are placed at street level on the truck flat-bed for safety. Such an arrangement will reduce the time spent in ground to platform communication purely to determine platform placement. Once initial elevation of the platform takes place all subsequent traverses can occur under direct control of the platform occupant.

10. Improved Navigation Sensitivity
    The Condor Lift supplied for the demonstration still used hydraulic feedback with pressure sensing to provide control of platform pitch, yaw and position. The latest versions of the Condor Lifts all use electronic sensing for maintaining platform balance. This makes the general ride in the platform smoother; and it also improves overall control of platform placement.
11. Improved Range of Motion for Full Operation of Lift
    The supplied lift was one which could only open for full elevation after first moving out to a 60° arc relative to the truck base. A newer Condor Lift has a reduced arc requirement of 45° relative to truck base before full extension is possible. This greatly reduces the size of the sphere within which the lift operates, in turn making the new lift more compatible with narrower dry-dock settings.
12. Improved Vertical Rotation of Platform
    The evaluated lift platform combination was restricted in the degree to which one could rotate the containment about the vertical axis at the end of the lift arm. This is primarily a restriction of the gimbal used in the supplied lift. A custom designed gimbal is proposed by the lift manufacturer, which opens up the range of vertical rotation of the platform mounting. This further reduces the effective footprint of the extended lift arm, making it more suited for dry-dock operation. At much closer approaches to a vessel direct perpendicular placement of the containment platform becomes possible.
13. Hose Control
    A system of self retracting reels handles the blasting hose and the grit recapture hosing, keeping them close to the boom. A telescopic array of vacuum hosing on the side of the boom allows it to remain out of the dock area also.
14. Condor and Carrier
    Condor can develop a telescopic straight boom aerial work platform with sufficient capacity, working height, and horizontal reach with a chassis dedicated to a narrow area set up and operation.
    The Condor would be mounted on the special “TUG” type chassis, and utilize “short jacking” and a 10 ft maximum outrigger spread to contain the unit into a “small as possible space.” Another possibility is to include the air compressor on the chassis. Air recapture, drying, and blasting equipment will be towed on a cart behind the Condor lift. The TUG will have all wheel steering, to make it maneuverable in tight areas.

E Estimated Cost Benefit Analysis from Shipyard Implementation of Improved Design

This section of the report presents a simple model for estimating the cost to implement the containment system evaluated in the study. The model presented can serve as the basis for determining the costs to implement other alternative surface preparation systems. Our example model compares the cost to implement the containment with recycled metallic media, (CRMM) with open air abrasive blasting, (OAAB). Costs are estimated for abrasive blasting to two levels of surface preparation, Near White Metal - SSPC-SP 10 and Brush-Off Blast - SSPC-SP 7.

1. General Approach for Cost Modeling

a) Cost Components

The cost elements used in these models include:

- Cost of capital equipment of components (amortized over five years).
- Cost of operation (maintenance, operation, shutdown, repair, utilities, etc.).
- Cost of consumable items (abrasive, hoses, nozzles).
- Costs for worker protection (PPEs and training).
- Costs for waste disposal.
- Labor costs for surface preparation.

The individual cost components used are described later in section E.2. In addition to cost data it was necessary to estimate the rate of cleaning in square feet per hour and the number of hours of production per year, for each surface preparation system. All cost data were converted to dollars per square foot of cleaning.

b) Sources for Data and Model

The specific costs and productivity assessments used in our model are derived from the following studies, projects and reports:

- Current project. Data on actual productivity achieved during the demonstration of the prototype containment structure and support equipment, (see Table 4 on page 25,) and costs for operating the containment.
- NSRP Report 0387 on "Use of Recyclable Metallic Media in Tank Blasting." This report provides the core of our cost model for converting costs of operation, and use of abrasive blasting systems, into costs per square foot.
- NSRP Project 3-95-7 "Users Guide to Selection of Abrasives." This study provides industry data on abrasive consumption and production rates for typical tasks. Data for a wide variety of mineral and metallic abrasives is presented.

c) Assumptions of Model

i) Limitations

There are many variables involved in shipyard surface preparation and coating. It is impossible to report the specific costs for all the possible tasks and equipment within each surface preparation system. The systems compared in this section are:

- OAAB -- Open Air Abrasive Blasting, and;
- CRMM -- Containment with Recycling of Metallic Media.

The costs for the systems are assessed for two levels of cleaning, SSPC-SP 10 “Near White Metal Blast Cleaning,” and SSPC-SP 7 “Brush-Off Blast Cleaning.”

ii) Assumptions Regarding Operating Conditions for OAAB

These are as follows:

(1) The abrasive is a mineral grit having a bulk density of approximately 100 lbs. per cubic foot.

(2) Abrasive blasting is done using a #8 (1/2 inch nozzle).

(3) Pressure at the nozzle is 100 psi.

(4) Abrasive is not recycled.

(5) Clean up of abrasive for waste disposal occurs once, at the end of each surface preparation session.

(6) The operator works from a platform supported on a scaffold which affords easy access to a large surface area.

(7) Equipment requirements are typical of those for any abrasive blasting operation.

iii) Assumptions Regarding Operating Conditions for CRMM

These are as follows:

(1) The abrasive is a metallic grit, with a density of 300 lbs/ft.^{3}.

(2) Abrasive blasting is done using a #8 (1/2 inch) nozzle.

(3) Pressure at the nozzles of 100 psi.

(4) Abrasive is constantly recycled, cleaned and reused with 90% recovery efficiency.

(5) The containment used is on a platform.

(6) The platform is moved after cleaning the small area open to the operator.

iv) Yearly Hours of Operation

There are 1500 work hours assumed per year for each surface preparation system. This figure for the number of hours of operation comes from NSRP Report 0387.

d) Converting Quantifiable Costs to Dollars For Each Square Foot of Cleaning

The data are presented as:

- Dollars per year of operation, or as;
- Dollars per hour of operation, and as;
- Dollars per square foot of cleaning.

In this section these numbers are all reduced down to a common base of dollars per square foot of cleaning. To accomplish this the following calculations are made:

- Dollars per year can be converted to dollars per hour by dividing the annual operating costs by the number of hours the equipment was used that year (i.e., 1500).
- Dollars per square foot are derived by dividing the dollars per hour of operation by the estimated number of square feet of cleaning per hour shown in the table "Productivity Rates for Surface Preparation Systems."
- Dollars per square foot of cleaning are used directly.

2. Derivation of Cost Components

a) Cost of Capital Equipment

In our model we assume that there are amortized capital costs for the equipment, whether it represents a new purchase or is likely to already be part of the shipyards inventory of equipment. For each system we list the equipment components required, assign estimated costs for procurement of those items of equipment, then amortize the costs over a five year time span.

i) Costs of Equipment for OAAB

The equipment costs for OAAB are tabulated below in Table 8. This data is taken from the NSRP Project Report 0387. It has been adjusted for inflation at 3% per year for the three years following the issuance of the report. This data does not include costs for nozzles and hoses which are treated as consumable items.

Table 8: Equipment Procurement Costs for OAAB & CRMM

	Approximate Purchase Cost	
Component	OAAB	CRMM
Air Compressor (1300 CFM Portable)	$70,000	$70,000
Blast Pot (Pressure Type)	$15,000	$15,000
Air Dryers and After Coolers	$2,000	$2,000
Moisture and Oil Separators	$1,000	$1,000
Dust Collector (12,000 CFM)	$55,000	$55,000
Abrasive Recycling Unit for Containment		$12,000
Grit Recycling and Cleaning Unit		$40,000
Vacuum Air Pump		$55,000
Containment Lift Device		$450,000
Total Equipment Costs	$143,000	$700,000

ii) Costs of Equipment for CRMM

The equipment costs for a CRMM system are based on the manufacturer data for the units used in Task C “Field Evaluation of a Prototype Combined Abrasive Recycling & Containment Unit” of this project, see Table 8. Data is also taken from the NSRP Project Report 0387.

iii) Amortized Capital Costs for the Two Systems

Taking the equipment procurement costs for each system defined above one can calculate the amortized cost of this capital investment over a five-year period. This results in an annualized cost for each equipment set, see Table 9 on page 39.

Table 9: Annualized Capital Equipment Costs

Surface Preparation System	Total Procurement	Annual Cost of Capital Equipment (a)
OAAB	$143,000	$30,342
CRMM	$700,000	$148,526

iv) Estimating Productivity of Each System

To reflect the incremental effect of equipment costs on the costs to clean each square foot of surface, one must know the overall productivity of each system. Industry data on the productivity of the two systems has been accumulated by SSPC for this and other NSRP Projects.

The assumed surface being cleaned is a multi-coat system (such as a 3-coat epoxy of 10-12 mils thickness).

Abrasive blasting productivity information is available from data produced in this report and from data in NSRP Project 3-95-7, "Users Guide to Selection of Abrasives."

Listed below in Table 10 are the estimated peak productivity rates for each of the systems under the operating conditions described earlier, for surface preparation to the two levels of cleanliness.

These costs are converted to costs per square foot of cleaning as follows.

Cost per Square Foot = Cost Per Year / (Hours of Use per Year x Square Feet of Cleaning Per Hour).

It is estimated that the unit will be used for 1500 hours each year. Typical production rates are given in the table below, along with the costs of equipment for each square foot of cleaning.

Table 10: Productivity Rates for Surface Preparation Systems

Surface Preparation System	Cleaning Rate SSPC-SP 10 ft^2/Hr	Equipment Cost $/$ft^2$ SSPC-SP 10	Cleaning Rate SSPC-SP 7 ft^2/Hr	Equipment Cost $/$ft^2$ SSPC-SP 7
OAAB	290	$ 0.10	2000	0.015
CRMM	190	$ 0.16	1300	0.023

b) Cost of Operation

The costs to operate each of the surface preparation systems varies in proportion to the number of pieces of equipment used and the fuel or utilities required for their operation. Other contributory operating costs include times for maintenance, training, down-time and repair. Operating costs depend on several factors such as; the utility requirements, power, fuel, and the relative amount of maintenance required. For our model analysis, we present

figures for OAAB and CRMM.

NOTE: Use of this cost modeling approach to determine the costs of other containment systems requires data on costs of operation. In the absence of such data we suggest that maintenance and operating costs be set at a fixed proportion of capital costs, say 30%. Users must recognize that such an arbitrary ratio significantly increases the estimated maintenance and operating expenses for surface preparation systems requiring large capital investments.

The overall productivity for the two systems reflects typical achievable cleaning rates during a full day of normal operation. This overall productivity thus accounts for all maintenance activities, set-up and shut-down times, normal stoppages for replenishing media or tool parts, and other required activities.

The elements for the costs of operation and their estimated amounts are shown below, (Table 11,) expressed in terms of dollars for each hour of equipment operation. The figures given combine operation, maintenance and training costs. They are derived from the figures given in NSRP Report 0387, adjusted for inflation, or from estimates made during the field trials of the CRMM prototype under the current project.

Table 11: Operation Costs for Each Surface Preparation System

	Costs for Operation $/Hr	
Cost Element	**OAAB**	**CRMM**
Air Compressor (1300 CFM Portable)	$32.00	$32.00
Blast Pot (Pressure Type)	$0.25	$0.25
Air Dryers and After Coolers	$1.50	$1.50
Moisture and Oil Separators	$0.25	$0.25
Dust Collector		$6.00
Grit Recycling and Cleaning Unit		$0.40
Vacuum Air Pump		$1.10
Containment High Lift Device		$6.15
Total Operating Cost	**$34.00**	**$47.65**
$ per ft^2 SSPC-SP 10	**$0.12**	**$0.25**
$ per ft^2 SSPC-SP 7	**$0.017**	**$0.037**

These can be converted to dollars per square foot of cleaning by dividing by the productivity estimates shown earlier in Table 10. The results of such a calculation are shown in Table 11, above.

c) Costs Of Consumable Items

These are presented below for each system in terms of dollars per hour. They are derived from the same sources used earlier. The major consumable for surface preparation is the abrasive as shown in Table 12, below. For OAAB the abrasive type is a non-metallic abrasive. The usage rate is estimated at 10 pounds per square foot of cleaning to achieve an SSPC-SP 10 “Near White Metal Blast Cleaning,” and 1.5 lbs per square foot to achieve an SSPC-SP 7 “Brush-Off Blast Cleaning” finish condition. CRMM uses metallic

abrasive. This has approximately three times the bulk density of many mineral abrasives, but can be reused quite efficiently. Assuming a conservative reuse rate of 90% on each recycle of metallic abrasive, typical cumulative use rates are 3 pounds per square foot for SSPC-SP 10 and 0.5 pounds per square foot for SSPC-SP 7 cleaning. Thus, typical use rates of mineral abrasive are 1.5 tons for each hour of cleaning, and roughly 0.3 tons per hour for metallic abrasive use. Based on a cost for metallic abrasive of $400 per ton, and mineral abrasive of $100 per ton, the relative costs per square foot for each level of cleaning are shown below. Costs for other consumable items (such as hoses, nozzles and other items) are minuscule, amounting to between $0.01 to $0.02 per square foot.

Table 12: Abrasive Cost for CRMM Compared to OAAB[a]

Costs for Abrasive $/ft^2		
Degree of Cleaning	OAAB	CRMM
SSPC-SP 10 Cleaning	$0.52	$0.60
SSPC-SP 7 Cleaning	$0.075	$0.088

a - If a less conservative recyclable factor is assumed then CRMM material costs are reduced.

d) Cost for Worker Protection

Worker protection costs include the costs for PPE (Personal Protective Equipment) and any added labor costs for training, plus added overhead costs for trainers and training materials. Shipyards have recurring costs for these items. It is assumed that all workers require basic PPE including ear, hearing, foot, head, and eye protection. Costs for equipment and training are not considered separately here. Additional training costs are incurred when workers are potentially exposed to hazardous materials such as lead or cadmium. Under conditions of expected exposure to such hazardous materials there are additional specific training and monitoring requirements. The nominal estimated cost for worker protection and training, when dealing with hazardous paint removal, is estimated at $1.00 per square foot for SSPC-SP 10 cleaning, $0.20 for SSPC-SP 7 cleaning. This is based on data from bridge and other lead paint removal projects. (This represents the low end of the range of costs for enhanced workplace monitoring, worker medical surveillance, and training to deal with hazardous materials. The actual reported range was between $1.00 to $4.00).

An added cost for worker protection is incurred when specific equipment is used. For example, when abrasive blasting hazardous metals in containment, an abrasive helmet with an enhanced protection factor of 1000 is preferred. The additional cost of such equipment is modest when measured in dollars for each square foot of cleaning. This cost amounts to less than $0.02 and is not considered here.

e) Costs for Waste Disposal

Costs for waste disposal depend on two factors. First, it must be determined if the waste is hazardous or non-hazardous. Second, there is a dependency on the degree of cleaning needed. The quantity of waste material per hour of operation remains nearly constant for both levels of cleaning. Other assumptions factoring into the calculations for waste disposal that apply to OAAB and CRMM include:

- Hazardous waste disposal cost. This is estimated at $240/ton ($0.12/lb) and does not include estimated transportation cost of $20/ton (up to 1000 miles), nor costs of laboratory tests to profile the waste.
- Non hazardous waste disposal cost. This is estimated at $50 per ton ($0.025/lb).

The quantity of waste disposed is assumed to be equivalent to the amount of abrasive consumed, see Section c on page 40:

* SSPC-SP 10 - Non-metallic abrasive consumption is 10 lbs per square foot.
* SSPC-SP 7 - Non-metallic abrasive consumption is 1.5 lbs per square foot.
* SSPC-SP 10 - Metallic abrasive consumption rate is 3 lbs per square foot.
* SSPC-SP 10 - Metallic abrasive consumption rate is 0.5 lbs per square foot.

The data presented in Table 13 indicates that this cost burden is only severe if the waste being disposed of is characterized as a hazardous waste.

Table 13: Waste Disposal Costs for Each Surface Preparation System (Dollars Per Square Foot).

Waste Type/ Degree of Cleaning	OAAB	CRMM
Hazardous/ SSPC-SP 10	$1.24	$0.38
Non-hazardous/ SSPC-SP 10	$0.21	$0.063
Hazardous/ SSPC-SP 7	$0.18	$0.055
Non-hazardous/ SSPC-SP 7	$0.030	$0.009

The square foot cost by is derived by multiplying the following three factors:

* The abrasive consumption rate (lbs/ft^2);
* The production rate (ft^2/hr,) and;
* The disposal cost ($/lb).

f) Labor Costs for Surface Preparation

We assume an average labor rate (including overhead) of $30 per hour. For each system and level of cleaning the cost per square foot of direct labor is computed by dividing the labor rate by the production rates shown in Table 10 on page 39.

3. Comparing Overall Costs of Blasting Systems

The results of these calculations are shown in Table 14 below for the major cost elements in our model.

The overall equation for cost per square foot of cleaned surface for each combination of desired level of cleaning (SSPC-SP 10 or SSPC-SP 7) with original material type (hazardous or non-hazardous) when achieved with either the OAAB or CRMM system is as follows:

Total cost per square foot (TCS) is the summation of Annualized Capital Cost of Equipment (ACC) + Equipment Operating Cost (OC) + Cost of Consumables (CC) + Worker Protection Cost (WPC) + Waste Disposal Costs (WDC) + Cost of Labor (LC)

TCS = ACC+OC+CC+WPC+WDC+LC

Table 14: Total Cost for Surface Preparation System Use

	Costs $/ft^2			
Cost Element	**OAAB**		**CRMM**	
	SSPC-SP 10	SSPC-SP 7	SSPC-SP 10	SSPC-SP 7
Annual Cost of Capital	$0.07	$0.01	$0.52	$0.08
Operating Costs	$0.12	$0.02	$0.25	$0.04
Costs of Consumables	$0.52	$0.08	$0.60	$0.09
Worker Protection Costs (Hazardous Only)	$1.00	$0.20	$1.00	$0.20
Waste Disposal Costs (Hazardous)	$1.24	$0.18	$0.38	$0.06
Waste Disposal Costs (Non-Hazardous)	$0.21	$0.03	$0.06	$0.01
Labor Costs	$0.10	$0.02	$0.16	$0.02
Total Costs (Non-Hazardous)	**$1.01**	**$0.15**	**$1.59**	**$0.23**
Total Costs (Hazardous)	**$3.05**	**$0.50**	**$2.91**	**$0.48**

This analysis indicates that CRMM is more cost effective as a surface preparation system only when there is a need to handle hazardous waste materials. One of the most questionable assumptions made in our estimate is the assignment of a 90% reuse factor for the metallic abrasive. This level of abrasive reuse matches our design goal. Enhancing the reuse level for the metallic abrasive would make CRMM more competitive. For example, if the reuse rate of the metallic abrasive is raised to 95% then the costs for consumables is cut in half to $0.30 for cleaning to SSPC-SP 10. Costs for disposal of non-hazardous waste are also reduced to $0.03. This brings the total cost of non-hazardous SSPC-SP 10 cleaning with CRMM to $1.26 per square foot. This is much closer to the cost for cleaning with OAAB under similar conditions of $1.01 per square foot. Also this model does not explicitly account for the reduction in dust with CRMM. This dust reduction can result in

an improved workplace for adjacent workers, improving their productivity.

4. Estimated Time for Return on Investment for a CRMM System

   Based on our cost modeling, there is only one scenario under which a shipyard will realize a return on their investment in the CRMM system relative to OAAB. The scenario requires the shipyard to regularly use the CRMM to remove paint containing hazardous materials. The time to reach a return on investment is dictated by the total procurement cost of the equipment, the production rate achieved when cleaning a surface, and the number of hours of use of the equipment. Using the assumptions for hours of equipment use and production rates from our model, the time for return on investment (ROI) in a CRMM system is calculated as follows:

   - Total System Procurement Cost ÷ (Cost Saving of CRMM over OAAB (Per Square Foot) x Hours of Use Per Year x Square Feet Cleaned Per Hour)

   The result of this calculation is shown below in Table 15.

Table 15: Estimated Time for ROI on CRMM System

	SSPC-SP 10	**SSPC-SP 7**
CRMM Cost Saving Over OAAB (Per Square Foot)	$0.14	$0.02
Hours of Use Per Year	1500	1500
Square Feet Cleaned Per Hour	190	1300
Cumulative Savings Per Year	$39,982	$35,371
Added System Procurement Cost [a]	$507,000	$507,000
Years to Break Even	**12.7**	**14.3**

a -The difference in cost between an OAAB and CRMM System

The pay-back period for return on investment is between 12.7 and 14.3 years, depending on the level of surface preparation achieved.

As noted earlier the model assumes a conservative reuse efficiency of 90%. Improving the abrasive reuse efficiency rate to 95% has a dramatic impact on the pay-back period for return on investment. The improved reuse rate for abrasive lowers consumable costs and costs for waste disposal with the CRMM system. CRMM becomes $0.63 cheaper per square foot for SSPC-SP 10 cleaning when hazardous waste is generated. The cost advantage of SSPC-SP 7 cleaning under similar conditions is also improved to $0.09 per square foot. The pay-back period for return on investment falls to just under three years in either case.

For the CRMM system to demonstrate a cost advantage per square foot over OAAB when removing non-hazardous paint even higher abrasive reuse rates are needed. Only when the abrasive reuse rate is 99% does CRMM become generally competitive with OAAB. Note though that the time to pay-back any return on investment becomes very long, over one hundred years.

V Conclusions & Recommendations

A Summary of Field Evaluation

1. Description of Prototype
   A lift mounted abrasive recycling and containment system was evaluated at a shipyard for 2 days. The system consisted of the following:
   - Containment type - mini-enclosure.
   - Dimensions - approximately 8 ft wide, 12 ft long, and 8 ft high (from working platform) [11 ft high (from base of abrasive recapture bin)].
   - Occupancy - able to accommodate two blasters, although in the demonstration only one blaster occupied the structure at any time to keep within new weight constraints.
   - Construction - rigid frame construction based on an ARK Systems Corporation 8’x8’x12’ space frame platform.
   - Waste collection - The ARK platform was configured with waste collection hoppers and aluminum gratings for the work decking. Waste and recyclable steel grit were transported from the hoppers by mechanical grit removal and pneumatic dust collection.
   - Membrane material - The containment membrane was an impermeable membrane (Monarflex™).
   - Membrane attachment to structure - Tied to a skeleton of 2 inch schedule 40 PVC tubing which was itself secured to the ARK platform.
   - Surface seals - Spring loaded pistons with added membrane material.
   - Lifting device - The prototype was lifted into position using a Condor truck mounted 125S-TC.
   - Attachment to lifting device - Fork extension made of 3/8-inch galvanized metal channel weighing 300 lbs. This was needed to accommodate the depth of the ARK platform as it attached to the Condor lifting device. (The election to use PVC tubing was a late design change required due to the incorporation of this added weight).
   - Platform control - Controls for the boom were mounted to the Condor lifting platform, this was a change from our original design concept. This change is not required in our revised design.
   - Dust collection - 12,000 CFM Ingersoll-Rand Compressor
   - Abrasive blasting pot - Standard abrasive blasting pot.
   - Media cleaning - VB1200 Media Recycler unit.
   - Compressed air - Ingersoll-Rand compressor.
   - Overall footprint of containment and lifting device - 25x40 ft.
2. Evaluation of Prototype
   The system was evaluated as follows
   - Dust emission: outside containment: <0.21 mg/m^3 (negligible impact on yard air quality;
   - Negative pressure in containment: 1.0 to 2.0 inches of water (industry standard is minimum of 0.03 in water);

- Worker protection from dust: 0.114-0.34 mg/m^3 (workers adequately protected);
- Air flow in containment: exceeded industry standard of 60ft/min downdraft;
- Blasting productivity: 1000-1200 ft^2/8-hr day;
- Degree of surface preparation: SSPC -SP10;
- Containment mobility: reposition in 4 to 6 minutes;
- Containment construction/erection time: 3 days;
- Abrasive cleanliness after recycling: Less than 0.5% non-metallic media, and;
- Number of recycles: maximum number of recycles 100, minimum number of recycles 30.

3. Comparing Performance vs. Design Goals
   Based on the above, we conclude that the evaluated containment met or exceeded all performance goals when it functioned properly. The key deficient area, a reduced level of abrasive reuse, occurs when the seals are not properly set. This deficiency is addressed in our improved design.

B Design Tools Delivered

There are two sets of design drawings submitted as part of this final report. The first set is the design as used in the field trials, complete with listings of materials and equipment. The second set is the design incorporating improvements made based on our field trials. These submittals are made as a set of AutoCAD files.

The design drawings and listings of equipment and material will permit any shipyard to procure the required items of equipment, fabricate the needed connections, and construct the containment system.

C Design Improvement

A total of fourteen design improvements were made as a result of lessons learned during the field trials. These changes included:

- Reduction in Containment Structure Dimensions
  - This reduces weight and improves mobility.
- Improved Bellows Seal Control
- Improved Bellows Construction
  - These changes will improve media retention and reuse.
- Improved Membrane Durability
  - This will reduce down-time for repairs.
- Improved Containment Visibility
  - The new membrane material has higher light transmission. This will also improve communication with an operator on the containment platform.
- Increased Rigidity of Containment Skeleton
  - This will improve overall strength and durability of the platform, which improves an already safe design.

- Improved Balancing of Containment Platform
    - * This also improves safety, moving the center of gravity back toward the lifting device. This also results in greater platform stability and allows for a smaller lifting device.
- Reduced Footprint for Lift
    - * The improved design reduces the overall footprint by as much as 40%. This will permit use in a larger range of dry-docks.
- Improved Operator Navigation of Platform
    - * The navigation controls are returned to the platform.
- Improved Navigation Sensitivity
    - * The navigation is aided by electronic self-leveling controls, an improvement on the demonstrated hydraulic controls.
- Improved Range of Motion for Full Operation of Lift
    - * The new lifting device has a lower minimum angle of lift before full motion is possible.
- Improved Vertical Rotation of Platform
    - * Reducing platform size and placing the platform back toward the lifting device allows for a larger range of platform motion around the vertical axis at the end of the lifting arm
- Simplified Hose Control
    - * Hoses are now run along the lifting arm, this reduces drag on the system.
- Optimized Lift and Carrier
    - * The new lifting device allows for many of the design improvements made here, in addition the new carrier is of higher base weight as it does not have to be a road-capable vehicle. This makes for a far more stable array.

D Computing Costs

The cost of this system was compared with the cost of the conventional practice of open abrasive blast cleaning in which nonmetallic abrasive is used once, collected and discarded.

The cost elements used in these models include:

- Cost of capital equipment of components (amortized over five years).
- Cost of operation (maintenance, operation, shutdown, repair, utilities, etc.).
- Cost of consumable items (abrasive, hoses, nozzles).
- Costs for worker protection (PPEs and training).
- Costs for waste disposal.
- Labor costs for surface preparation.

The overall equation for two levels of cleaning (SSPC-SP 10 or SSPC-SP 7) when achieved with either the OAAB or CRMM system is as follows:

Total cost (TC) is = Annualized Capital Cost of Equipment (ACC) + Equipment Operating Cost (OC) + Cost of Consumables (CC) + Worker Protection Cost (WPC) + Waste Disposal Costs (WDC) + Cost of Labor (LC)

TC = ACC+OC+CC+WPC+WDC+LC

Based on calculations made using this type of modeling, the overall costs per square foot for the two alternatives were computed. These costs are shown below.

Table 16: Total Cost for Surface Preparation System Use

	Costs $/ft^2			
Cost Element	**OAAB**		**CRMM**	
	SSPC-SP 10	SSPC-SP 7	SSPC-SP 10	SSPC-SP 7
Annual Cost of Capital	$0.07	$0.01	$0.52	$0.08
Operating Costs	$0.12	$0.02	$0.25	$0.04
Costs of Consumables	$0.52	$0.08	$0.60	$0.09
Worker Protection Costs (Hazardous Only)	$1.00	$0.20	$1.00	$0.20
Waste Disposal Costs (Hazardous)	$1.24	$0.18	$0.38	$0.06
Waste Disposal Costs (Non-Hazardous)	$0.21	$0.03	$0.06	$0.01
Labor Costs	$0.10	$0.02	$0.16	$0.02
Total Costs (Non-Hazardous)	**$1.01**	**$0.15**	**$1.59**	**$0.23**
Total Costs (Hazardous)	**$3.05**	**$0.50**	**$2.91**	**$0.48**

Overall the abrasive containment and recycling system is a viable option for shipyard surface preparation work.

E Implementation of Results

1. Key Applications Identified
   The primary suggested use for the containment is in cleaning of ship hulls. This is true for removal of all the paint, or when conducting partial hull coating removal. No investigation was made of the use of the containment to enclose spray painting, though this would improve its range of application.
2. Economic Analysis
   The decision on procuring the system described is based on the relative benefits vs. the costs.
   The improved containment and recycling unit design represents a significant capital investment. The biggest contribution to the cost for the containment unit is the lifting device whose cost is assumed to be amortized over 5 years.

The major benefits of the improved containment and recycling unit are:

- Reduced waste production;
- Ease of waste cleanup, and;
- Reduction of dust in general work area.

The major disadvantages are

- increased cost per ft^2;
- large capital outlay, and;
- reduced overall production rate.

Even when open air abrasive blasting is marginally cheaper than the use of the containment system there are other benefits. These benefits include reduction in the re-work of adjacent painted areas, limited intrusion on the work of other trades, and a general improvement in the overall workplace environment.

In some instances the containment system may prove to be more cost effective. For example:

- When removing a coating with hazardous constituents (e.g. lead, chromate, organotin) which may result in waste being classed as a hazardous.
- When adjacent operation could be adversely affected by dust and could delay blast cleaning.

3. Procedure for Implementation

A shipyard interested in implementing this solution should take the following steps:

- Determine the need for implementation and expected degree of use.
- Examine the design drawings for the improved containment system, and:
    - Determine if the footprint for the design matches with available space in a dry-dock or similar shipyard area. The new design calls for a 20x30 ft foot-print. If insufficient space exists in the dry-dock it may be possible to use the containment from a dock-side location.
    - Determine if added equipment acquisitions are needed or if adequate support equipment exists on site.
- Have an HVAC engineer or equipment representative design a balanced ventilation system consisting of dust collector, compressor media recycling unit and hose arrays for the containment system.
    - This is a critical step. Failure to properly balance air supply, dust collection and ventilation demands will “starve” the system, drastically reducing its efficiency.
    - The most important piece of support equipment for ventilation is the dust collector; a capacity of 12,000 CFM is highly recommended.
- Determine availability of the containment platform.
- Determine nature of containment material, and if the improved design calls for more durable plexiglass screens. A flexible membrane is also well suited but will result in higher repair times.
- Determine nature of seal material - a flexible bellows seal made from membrane material was used in the demonstration. A brush seal is preferred for maximum media

retention.

- Assign time and costs to the training of operators in use of navigation controls for the containment system.
- Budget the costs for system acquisition, construction and use (the cost model is helpful in this regard).
- Estimate the time for Return on Investment (ROI) in a CRMM system.

VI Acknowledgments

A Assistance During Design and Evaluation of Containment

Special appreciation goes to Mr. Steve Cogswell of Atlantic Marine Shipyard, and his colleagues in the paint department, for assistance during the containment demonstration. Thanks also go to the management of Atlantic Marine Shipyard for providing the facility where the prototype demonstration was performed. The assistance of the Atlantic Marine fabricating shops in furnishing the bracket extension used in the containment demonstration is greatly appreciated.

Joe Harris of Infrastructures Technologies Incorporated (ITI) played a prominent role in setting up the demonstration, securing the equipment and vendor support, generating the AutoCad drawings, and collecting data during the demonstration. ITI was our designated design house for the prototype and revised containment designs. ITI’s associate, Wes Harvey, provided technical assistance with the containment system HVAC units and construction expertise during the demonstration phase.

John Meacham of Peterson Builders Incorporated (PBI) provided valuable guidance as the program manager.

John Kern of Norfolk Naval Shipyard provided contacts necessary to acquire demonstration site information. He was also instrumental in securing the cooperation of Atlantic Marine Shipyard for the demonstration.

Companies that provided equipment and services necessary to perform the prototype demonstration are: DynCorp (air monitoring and chemical analyses), Ervin Industries (steel abrasive), Monarflex (containment membrane), Ingersoll-Rand (dust collection), Condor (lifting device), Spider Staging (ARK system platform).

B Assistance During Information Retrieval

In addition to those mentioned above, the following companies also provided valuable information by responding to surveys and replying to other inquires: NASSCO (National Steel and Shipbuilding Company), Bath Iron Works, Avondale Industries, Atlantic Marine Alabama Shipyard, Norshipco, Beth Ship, North Florida Shipyard, Puget Sound Naval Shipyard, Twin City Dry Dock, Newport News Shipbuilding, Metro Machine, Ingalls Shipyard, Charleston Naval Shipyard, CASRM (Center for Advanced Ship Repair and Maintenance), Sea-Master Marine, PRC/MTO (PRC/Marine Transportation Organization, Alaska Ship and Drydock, NSWC-CD (Naval Surface Warfare Center - Carderock Division), PERA(CV) (Planning and Engineering of Repairs and Alterations {Carrier Vessels}), SAIC/AMSEC (Science Applications International Corporation / Advanced Marine Science and Engineering Center), PCCI Marine and Environmental Engineering, NSWC-PHD (Port Hueneme Division - Naval Surface Warfare Center), Trinity Industries, Mann’s Harbor Shipyard, Brooklyn Naval Yard, and Braswell Shipyards.

VII Supplementary Material

A Information Search Material

A report describing an information search conducted as the first phase of this project is available from program management (Peterson Builders). The Task A report includes a review of the technical literature as well as information gathered from industry sources. Shipyard surveys provided information on working conditions, necessary clearance in the drydock, and other engineering controls. This activity also provided information on typical equipment available at various sites. Pertinent information was gathered from contractors engaged in lead paint removal from highway bridges and water tanks. The contractor information described state-of-the-art containment systems used in general industry.

B Preliminary Design Drawings

Based on the information gathered, a combination of existing system components was defined in a system selection statement. This provided the basis for choices made during the design and evaluation phase.The preliminary design drawings of the containment are available in writing or as an electronic AutoCAD file from program management (Peterson Builders).

C Report on Containment Design and Field Evaluation

The report on Task C of this project contains new drawings for the containment that was actually tested. This report also contains the data and the analysis of the data collected at the prototype demonstration. The objectives of Task C included an outline of the design goals and expected containment capabilities. The report provided a complete description of design and performance goal attainment based on the field trials. Design improvements based on field trials are described. An estimation of return on investment is made for the implementation of the improved design. The Task C report, which includes the drawings and AutoCAD files, is available from program management.

D Revised Containment Design Drawings

As a result of the demonstration, modifications to the containment were suggested. These modifications are incorporated into the revised containment design drawings that are attached to this report.

Additional copies of this report can be obtained from the
National Shipbuilding Research and Documentation Center:

http://www.nsnet.com/docctr/

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